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Multi-criteria GIS-based siting of transfer station for municipal solid waste: The case of Kumasi Metropolitan Area, Ghana

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Abstract

The 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, waste transfer stations are used. The Kumasi Metropolitan Area, even though it has an engineered landfill, is faced with the problem of waste collection from the generation centres to the final disposal site. Thus in this study, multi-criteria decision analysis incorporated into a geographic information system was used to determine potential waste transfer station sites. The key result established 11 sites located within six different sub-metros. This result can be used by decision makers for site selection of the waste transfer stations after taking into account other relevant ecological and economic factors.

Keywords

Municipal solid waste, waste transfer station, multi-criteria decision analysis, GIS, waste management system, selection criteria

Introduction

Municipal solid waste (MSW) is generated by households, businesses, institutions and industry. MSW typically contains a wide variety of materials including discarded containers, packaging, food wastes and paper products. It includes a mixture of putrescible (easily degradable) and non-putrescible (inert) materials (USEPA, 2002). Management and disposal of such waste is a major challenge worldwide, particularly in highly urbanized areas and in developing countries (Washburn, 2012). Despite significant efforts made by some countries in recent decades to improve solid waste management services, most municipalities and metropolitan cities in developing countries still face major challenges in properly handling the increasing volume of waste produced. Increasing population, economic activities, urbanization and industrialization especially in developing countries such as those in Africa, have drastically increased the amount of waste generated.

Over the years, due to rapid urbanization, many existing disposal sites have been encircled by settlements and housing estates. The environmental degradation associated with these dumps directly affects the population with the consequence that disposal sites are subject to growing public opposition. This, together with the unavailability of land, is one of the reasons why obtaining sites for new landfills is becoming increasingly difficult. Finding a site for a new landfill far away from the urban area may have the advantage of less public opposition. However, it also means that the site is far away from the source of waste generation, thus increasing transfer costs and needing additional investments in the infrastructure of roads, hence intensifying the financial problems of the responsible authorities (Zurbrügg, 2002).

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 program and a final waste management system. There may be significant differences 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 shipment to a final waste management system. The basic type of transfer station has a designated receiving area where waste is unloaded, often compacted and reloaded into larger high volume vehicles, usually in a matter of hours (Öberg, 2011; USEPA, 2002). Bovea et al. (2007) described waste transfer stations as an integral part of present-day MSW management systems. The main criteria used to decide on the location of a transfer station has traditionally been the minimization of transport costs, as it is cheaper to transport great amounts of waste over long distances in large loads compared with small 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

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larger truck. Gil and Kellerman (1989) discussed three reasons why transfer stations are useful: (1) small or medium-sized communities may not generate sufficient waste to support a disposal facility; (2) if the distance to the disposal plant is great, the use of small collection trucks may be unnecessarily high; and (3) the location of a single disposal plant in a remote location to serve several communities will remove negative environmental impacts from residential areas.

Site selection for waste transfer stations is a complex process that requires careful consideration of a number of environmental features of the area. Rafiee et al. (2011) demonstrated the use of multi-criteria evaluation (MCE) for site selection of waste transfer stations in Mashhad City; this site selection included regional and environmental factors. According to Boroushaki and Malczewski (2010), geographic information system (GIS)-based multi-criteria decision analysis (GIS-MCDA) can be defined as a process that transforms and combines geographical data (map criteria) and value judgments (decision-makers' preferences) to obtain relevant information for decision making. Literature abounds on the use of GIS-MCDA for siting solid waste management facilities such as a landfill site, a waste transfer station and a waste treatment plant (Alanbari et al., 2014; DeAngelo, 2004; Eskandari et al., 2012; Khan and Samadder, 2014; Nas et al., 2009; Yazdani et al., 2015). Eskandari et al. (2012) adopted a multi criteria approach to locate a landfill in a conflicting economic, environmental and socio-cultural area. In their work, they used 13 constraints and 15 factors (of which only six were spatial factors), which were categorized into three classes of environmental, economic and socio-cultural factors. Using an analytical hierarchy process (AHP) and ranking order methods, the weight of the criteria were determined. Nas et al. (2009) also used eight map layers to carry out a suitability analysis using MCE analysis to locate appropriate landfill sites in Cumra County of Konya City in Turkey. Khan and Samadder (2014) reviewed various aspects of MSW management using GIS coupled with other tools such as weighted linear composition (WLC), MCE, MCDA, AHP and fuzzy multi-criteria decision making (FMCDM). Their research discussed the outstanding features of each of these integrated tools with GIS, and addresses how GIS can be used in the optimization of routes for solid waste collection from transfer stations to the final disposal site, in order to reduce the overall cost of solid waste management.

The main rationale behind integrating GIS and MCDA is that these two distinct areas of research can complement each other. While GIS is commonly recognized as a powerful and integrated tool with unique capabilities for storing, manipulating, analysing and visualizing spatial data for decision making, MCDA provides a rich collection of procedures and algorithms for structuring decision problems, designing, evaluating and prioritizing alternative decisions (Boroushaki and Malczewski, 2010; Malczewski, 1999). This study therefore aimed at identifying criteria for the siting of waste transfer stations suitable and applicable to the study area. Based on the identified criteria, suitable locations of waste transfer stations were determined.

Materials and methods

Study area

Size and location. Kumasi Metropolitan Area (KMA) is located in the transitional forest zone, about 270 km from the national capital, Accra. It covers a total land area of 254 km^2, stretching between latitude 6°21'N and 6°40'N and longitude 1°18'W and 1°21'W, with an elevation ranging between 250 and 300 m above sea level. KMA 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. Its beautiful layout and greenery environment has brought about the accolade 'The Garden City of West Africa'. Kumasi has grown in a concentric form to cover an area of approximately 10 km 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 (GSS, 2013; KMA, 2015). Figure 1 is a location map of the study area.

Population and demography. 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 national capital. The population of the area increased from 1 170 270 in 2000 to 2 035 064 in 2010 showing an increase of 86 4794 over the 10-year period (GSS, 2013). The fast population growth in the area would be attributed to Kumasi being the regional capital of the Ashanti region as well as the most commercialized 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. It has been estimated to have a daytime population of about 2 million (KMA, 2015).

Sanitation and waste management. As a result of the fast population growth and rapid urbanization occurring within the Metropolis, KMA is faced with several waste management challenges. The current domestic waste generation in Kumasi based on the 2006 projected population of 1 610 867 is 1000 tonnes. Collection of solid waste within the Metropolis is carried out mainly by private company under three main methods, namely house-to-house solid waste collection, communal solid waste collection, and institutional and industrial premises solid waste collection. A well-engineered sanitary site is in use at Dompoase, where refuse is disposed of, compacted and covered at the site. A weighbridge is also available and attached to a control room, where the refuse is weighed and inspected before being accepted into the landfill (KMA, 2015).

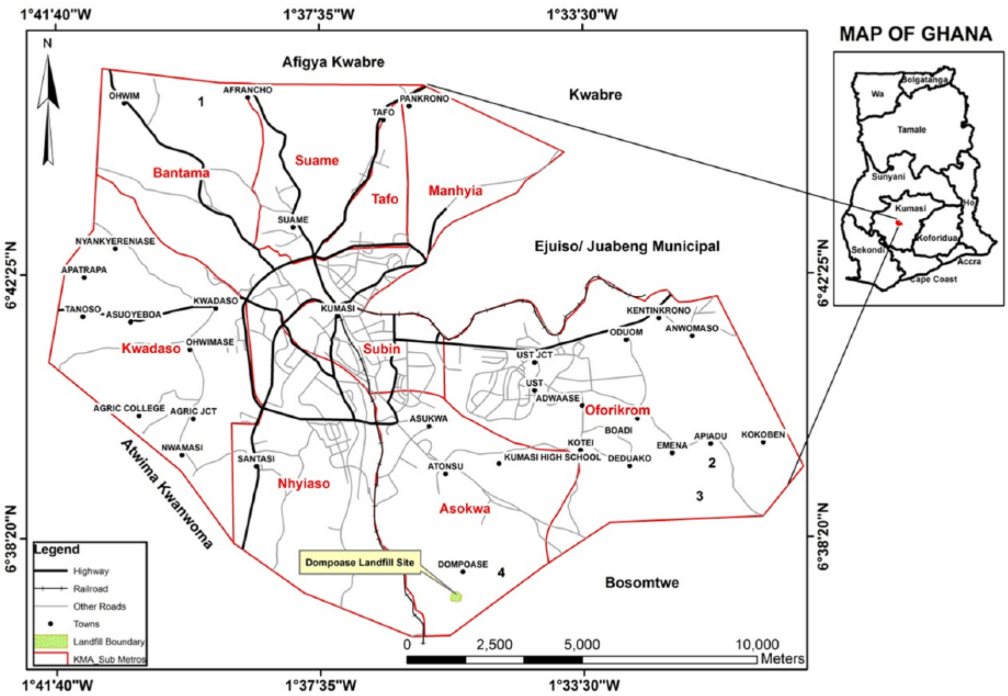

Figure 1. Location map of study area.

Table 1. Data types used for the study.

Data	Date obtained	Scale	Source
Aerial photograph	2007	1:50 000	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 Department, Kumasi
GPS coordinates	2013	126 Points	Field mapping

Materials

Much available data, both soft and hard copies at different scales, were used during this study, gathered from different sectors of the country. Data used was based on its availability and suitability for the purpose of the study. Table 1 shows the data types together with their sources that were used for the study.

Methods

This research made use of the WLC method in a GIS environment. The WLC method is one of the most widely used GIS-based decision rules (Eastman et al., 1993; Hopkins, 1977; Malczewski, 2000; Rafiee et al., 2011). The method is often applied in land use/suitability analysis, site selection and resource evaluation problems (Eastman et al., 1995). The basic reason for the popular use of this method lies in it being easy to implement within the GIS environment using a cartographic modelling approach and map algebra operation. The method is also easy-to-understand and intuitively appealing to decision makers (Malczewski, 2000).

Using this methodology, the procedure was applied through four main stages. First, the criteria to be used for siting the transfer station were considered. After determining the criteria, various attributes about each criterion was developed and standardized unto a common scale. Relative importance weight or percentage of influence of each criterion was additionally determined and finally, the weighted criteria were combined and overlay through an overlay analysis.

Determination of data types and selection of criteria. The selection of the criteria is essential in any site selection project as the reliability of the site would largely depend on it. The criteria were selected after a thorough review of available literature and consultation with experts. One of the proven guidelines for the selection of waste transfer station is a manual developed by the USEPA. This document clearly outlines the specific factor and constraint criteria that should be considered in selecting a situation site for a waste transfer station (USEPA, 2004). Therefore, this document served as the basis for the criteria that were selected for this study. USEPA (2004) categorizes the criteria into three sets, namely: (1) exclusionary siting criteria, (2) technical siting criteria and (3) community specific criteria.

Exclusionary criteria prevent siting a waste transfer station or any facility in areas prohibited by law or regulations. Such areas

Table 2. Criteria that were used with their grouping.

Dataset	Less suitable (1)	Averagely suitable (2)	Highly suitable (3)
Distance to highway	<500 m/>4000 m	500–1000 m	1000–4000 m
Distance to residential area	<500 m	500–2000 m	>2000 m
Distance to river/streams	<500 m	500–2500 m	>2500 m
Geology	Granitoid		Phyllite, schist
Slope	>9°	6–9°	<6°
Distance to faults	<1000 m	1000–4000 m	>1000 m
Distance from generation centres	>5000 m	500–1000 m	1000–4000 m

may include parks and reserves, wetlands and floodplains (USEPA, 2004). In this research, such criteria refer to the constraint criteria that were considered. The second set of criteria to consider consists of technical parameters that define the best potential facility sites. From these criteria, specific and definite engineering, operation and transportation conditions are provided. Such consideration ensures that potential areas are feasible (USEPA, 2004). In this research, the technical factors that were considered can be seen in Table 2 (specific examples include distance to fault zone and geology type). The final and last group of criteria assist in determining the impact of the facility on surrounding communities. All these criteria were considered during the selection process.

However, it is important to emphasize that some of the criteria outlined in the USEPA guideline were not applicable to the study area and therefore may not have been considered. Rafiee et al. (2011) sited a waste transfer station by using eight criteria. This research adopts all the criteria that they used except the soil criteria. The soil criterion was left out because the study area consists of one soil type (acrisols) and therefore using it will have no effect on the selected site.

The selection of the criteria also involved the development of a database for evaluating the criteria. Additionally, the selection of criteria was also based on the availability of the necessary datasets. The criteria that were selected were grouped into three categories of suitability or desirability, namely less suitable, averagely suitable and highly suitable. Table 2 shows the criteria that were adopted for this research.

Deriving datasets. After determining the various criteria to be used, there was the need to derive datasets for the individual data based on the criteria. Two types of datasets were derived: (1) the slope from the digital elevation model (DEM) in degrees and (2) distances for all the other data.

Deriving slope. As the area is generally undulating with mountains and valleys, there was the need to find areas that are relatively flat on which to build the waste transfer station; therefore, the slope of the land was considered. Slope class was determined from a DEM for the study area using degree as the measurement output.

Deriving distances. Apart from the DEM (slope) and geology datasets, distances were created for all the datasets shown in Table 2. This was necessary because the new site should a certain distance from the locations of concern. In deriving these datasets, Euclidean distance, which is a straight-line distance, was applied on each of those datasets. Thus, a straight-line distance was calculated for highway, residential area, rivers/streams, faults and waste generation centres datasets.

Reclassifying datasets. Deriving datasets, such as distance to highway, is the first step when building a suitable model. Each of the cells in the study area now has a value for each input criteria (slope, distance to highway, distance to residential area, distance to rivers/streams, distance to fault zones, distance to waste generation centres and geology). At this stage, it was practically impossible to combine the derived datasets, hence the need for reclassification of each of the individual datasets. For instance, combining a cell value in which slope is 5° with a cell value for distance to highway of 700 m to obtain a meaningful answer that can be compared with other locations is impossible.

Thus, to combine datasets, there was the need to first classify all the individual datasets on a common measurement scale such as 1 to 3. This common measurement scale is what determines how suitable a particular location (each cell) is for siting the new waste transfer station. Higher values indicate more suitable locations, whereas lower values indicate a less suitable area. For this particular study, all the datasets were reclassified into three classes: (1) for less suitable areas, (2) for averagely suitable areas and (3) for highly suitable area.

The values in the datasets that were derived in the previous step were all floating-point, continuous datasets, categorized into ranges and needed to be classified so that each range of values is assigned one discrete integer value such as 1 or 2 or 3, according to the measurement scale. This is because the inputs of the weighted overlay, which would be used in the next step, must contain discrete integer values. The derived datasets were reclassified into three classes according Table 2.

Weighing and combining datasets. To assign weights, seven criteria that 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 may 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). In this research, the latter method was adopted.

Several methods are available by which the relative weight of each criterion can be determined; these include the ranking method, the ratio method, the trade-off analysis method and the pairwise comparison method (Malczewski, 1999). In this research, 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). Saaty (1980) proposed the pairwise comparison method in the context of the analytical hierarchy process. According to him, this method is an effective method for the determination of relative importance. The method uses a ratio matrix to compare one criterion with another. Additionally, it uses a numerical scale with values ranging from 1 to 9, as shown in Table 3.

With the technique proposed by Saaty (1980), the weights were derived by normalizing the eigenvector of the square reciprocal matrix of pairwise comparison between criteria. The consistency of the weighting should be evaluated. In doing so, Saaty (1980) developed a consistency ratio (CR) index. The CR is a measure that provides a departure from consistency, and Saaty (1980) suggested that for a CR larger than 0.1, the matrix should be re-evaluated (Drobne and Lisec, 2009; Rafiee et al., 2011).

Experts and decision makers were consulted to fill the comparison matrix. Five waste management experts and decision makers were consulted, three with master degree in civil and sanitation engineering, and two senior staff of the waste management department of KMA. The five people were made to fill the comparison matrix independently after which the final weight was computed. Using the procedure described by Malczewski (1999), the weights for all the seven criteria were determine as shown in Table 4.

In calculating the final weight, there exist a wide variety of approaches; however, two of them are mostly applied, these are the lambda max and the geometric mean approaches (Kordi and Brandt, 2012). To use the lambda max technique, a vector of the weight ought to be defined as the normalized eigenvector corresponding to the largest eigenvalue, λ_{max}. If the weights are shown as a vector w consisting of w_i (i=1, 2, …, n), they are calculated as follows: $C\times w=\lambda_{max}\times w$, where C is the pairwise comparison matrix of the criteria, w is the vector of weights and λ_{max} is the largest, or principal, eigenvalue of C. To simplify calculating eigenvectors in the lambda max technique, Malczewski (1999) has developed an approximation of the eigenvector associated with the maximum eigenvalue. The accuracy of this approximation is increased when the pairwise comparison matrix has a low CR (Kordi and Brandt, 2012). Unlike the lambda technique, the first thing to do when using the geometric mean technique is to determine the geometric mean of each row of the pairwise comparison matrix according to Eq. 1 shown below (Kordi and Brandt, 2012; Buckley, 1985a, 1985b).

$$r_i = \prod_{j=1}^{n}(a_{ij})^{i/n} \tag{1}$$

where a_{ij} (i, j=1, …, n; n is the number of rows and columns and i and j are identifiers of a row and column, respectively) are the comparison ratios (element of the pairwise comparison matrix) and n is number of the criteria. After this, Eq. 2 is used to compute the final weight of each criterion:

$$w_i = \frac{r_i}{\sum_j r_j} \tag{2}$$

According to literature, a number of controversies has arisen on the use of either the lambda max or the geometric mean techniques (Buckley et al., 2001; Chang et al., 2008). However according to Buckley (1985a) in the lambda technique, it is sometimes challenging computing the eigenvector and difficult to arrive at a decision of selecting one criteria over the other.

Table 3. 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

Sources: Malczewski (1999) and Rafiee et al. (2011).

Table 4. Result of weight determination (consistency ratio=0.057).

Criteria	1	2	3	4	5	6	7	Weight
(1) Distance to highway	1	1/3	1/5	2	1/3	1/2	1/2	0.0622
(2) Distance to residential area	3	1	3	8	2	4	2	0.2954
(3) Distance to rivers and streams	5	1/3	1	7	1/2	3	1/2	0.1579
(4) Geology	1/2	1/8	1/7	1	1/7	1/5	1/6	0.0265
(5) Slope	3	1/2	2	7	1	3	1/2	0.1762
(6) Distance to faults	2	1/4	1/3	5	1/3	1	1/3	0.0812
(7) Distance from generation centres	2	1/2	2	6	2	3	1	0.2005

Barzilai (1997) and Crawford and Williams (1985) had more preference for the geometric mean over the lambda max. Barzilai (1997) particularly was of the view that the geometric mean was the only acceptable solution to the challenge of deriving weights when using the AHP's pairwise comparisons. Additionally, Buckley (1985a) also indicated that in the case of a consistent pairwise comparison matrix, the geometric mean method always produces the same weights as the lambda max technique. Kordi and Brandt (2012) carried out research to investigate how the geometric mean and the lambda max technique differ in the context of fuzzy AHP. They observed that, when using only a crisp pairwise comparison matrix, the results differ only slightly between the geometric mean and the lambda max AHP methods. Based on these literatures, we adopted the geometric mean technique in estimating the final weights.

Following the calculation of weight, CR was estimated and found to be 5.7%, which is less than the 10% proposed by Saaty (1980) and therefore found to be accepted. Therefore, there was no need to re-evaluate the matrix.

After calculation of weight, there was the need to combine all the weighted criteria to obtain a suitability map. According to Rafiee et al. (2011), there are several methods with which to combine the criteria and calculate the suitability index. Boolean intersection (BI), WLC and ordered weighting average (OWA) are the most common procedures. In this study, the WLC method, which is based on a weighted average that can easily be implemented in a raster GIS environment, was applied. By obtaining the summation of the product of the relative importance weight (percentage of influence) of each criterion with its standard suitability score, a suitability index was determined using Eq. 3 shown below.

$$SI = \sum w_i s_i \tag{3}$$

where SI is the suitability index, w_i is the relative importance of criterion i and s_i is the standard suitability score of criterion i. During the usage of the WLC method, an evaluation scale was set. As a measurement scale of 1–3 was used during the reclassification of the dataset, the evaluation set was also set at 1–3 by 1. As the datasets were classified into three classes, there was the need to use the same scale and range for the overlay analysis, therefore the 1 represent the range of moving from one class to the next successive class, so that the number of classes will be three. Thus moving from one class to the other requires an addition of 1.

Selecting optimal site. After getting the suitability index, a constraint map consisting of buffers around some importance public amenities such as major education centres, airport and recreation sites (Table 5) was obtained by applying a Boolean logic. This Boolean constraint map was subsequently used to determine the suitability score according to Eq. 4

$$Suitability = \sum w_i x_i \prod C_j \tag{4}$$

Table 5. Constraints applied.

Amenity	Name	Constraint
Education	Kwame Nkrumah University of Science and Technology	500 m buffer
Recreation Centre	Kumasi Children's Park	500 m buffer
Palace	Manhyia Palace	500 m buffer
Airport	Kumasi Airport	1000 m buffer

where C_j is the score of constraint j and $\prod$ is the product sign for the constraints, meaning that the product of constraints is ultimately multiplied by the summation of $w_i x_i$.

In order to determine and select optimal sites from the highly suitable areas, a minimum area and minimum optimality threshold was applied to the suitability map. Using several map algebra techniques, the highly suitable areas (places with a suitability score of 3) was selected. A minimum area of 1.62 ha was further applied to select the optimal sites. Rafiee et al. (2011) determined a land size of 10 ha as the total area required for a waste transfer station without offering any basis for this choice. In determining the minimum size of an optimal site, the approached described in the USEPA's 'Waste transfer stations: a manual for decision making' for determining the transfer station's capacity was adopted. According to the USEPA (2004), 'a useful exercise is calculating how much tipping floor space a facility would require to store a full day's waste in case of extreme emergence'. Thus, in the research, the tipping floor space (TFS) was determined.

In determining this space, one approach is to begin with an area of 371.61 m² and add to it 1.86 m² per each tonne of waste received in a day (assuming the waste will be temporarily piled 0.56 m² high on the tipping floor (USEPA, 2004). In this research, as the projected waste per day is 1000 tonnes, the required TFS was determined as shown below:

$$\text{TFS} = 371.61 \text{ m}^2 + 1000 \text{ tonnes TPD} \times 1.86 \text{ m}^2\text{tonne}^{-1} = 2,229.67 \text{ m}^2$$

where TPD is tonnes per day. In order to ensure that there is no queuing at the facility, an additional offsite area twice the size of the TFS was added. No convention exists for determining the size of this offsite area and therefore this size was selected after consulting traffic and waste management experts, as well as decision makers in the KMA. Additionally, as there will be the construction of additionally facility such as offices and a weighing bridge among others, a land size of 6689.02 m² was apportioned for this purpose. This additional land will provide enough space for future expansion of the waste transfer station. Therefore, a total of 13 378.07 m² equivalent to 1.34 ha was determined out of this process; however, this figure was approximated to 1.62 ha as the minimum size of the waste transfer station. To reduce the number of selected optimal sites, a cluster analysis was performed on the waste generation

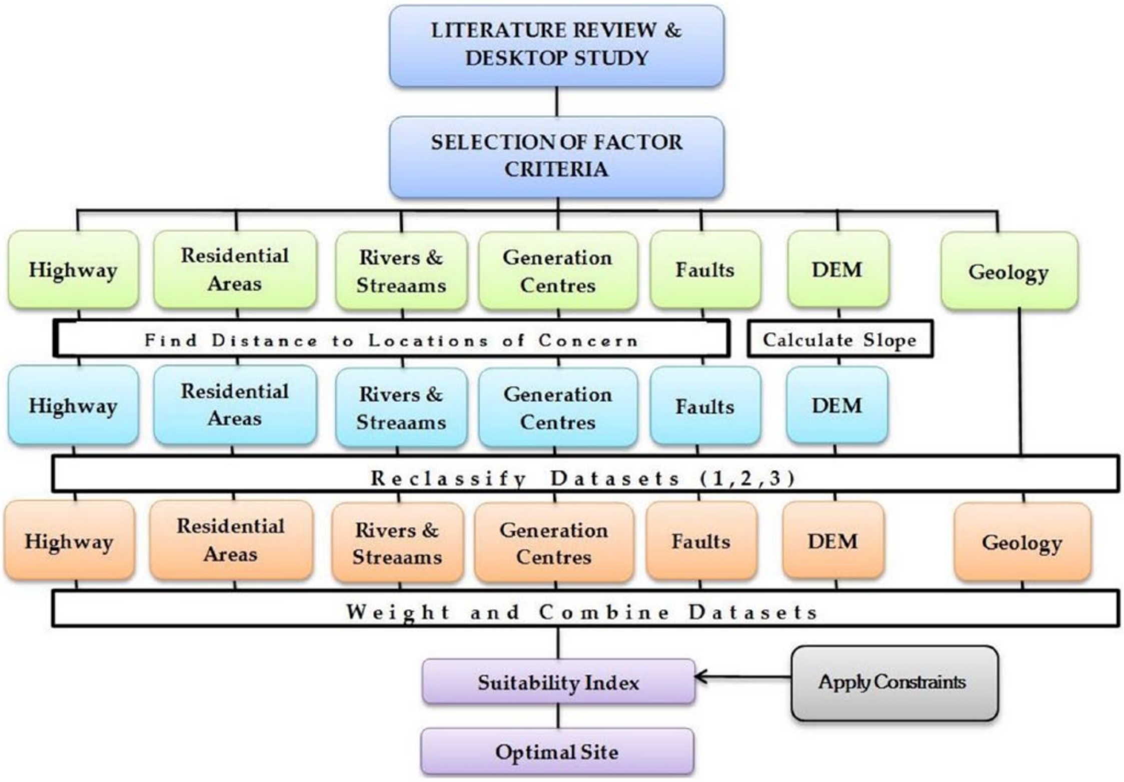

Figure 2. Flowchart of research methodology.

centres to identify hotspots of waste generation. This assisted in determining locations where the waste generation centres had significantly high clusters so the waste transfer station were located within these clusters. After this, near analysis was performed to determine the distances between the selected optimal site and the final waste disposal sites, this further assisted in increasing the optimality of the sites and thus reduces the number of selected sites.

Figure 2 is a flowchart that summarizes the research methodology adopted.

Results and discussions

Results

The methodology employed in this project resulted in the creation of suitability maps for the various criteria used. Maps show less suitable, averagely suitable and highly 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.

Deriving and reclassifying dataset. Figure 3 and Table 6 show the suitable index map and their areal extent, respectively.

Suitability index. 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 less suitable, 117.11 km^2 representing 57.5% was classified as averagely suitable and 21.695 km^2 representing 10.6% was classified as highly suitable. Figure 4 and Table 7 shows the suitability index map and its areal extent of the study area, respectively.

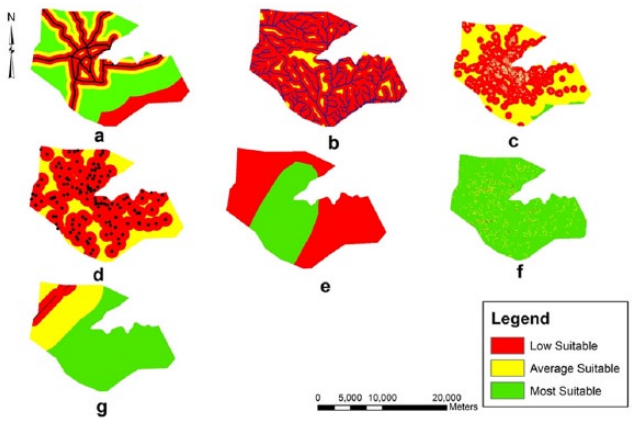

Figure 3. Maps showing suitability of evaluated criteria for waste transfer station: (a) distance to highway; (b) distance to rivers/streams; (c) distance to residential areas; (d) distance to water generation centres; (e) geological map; (f) slope map; (g) distance to fault zone).

Optimal sites. Using a minimum land size area of 1.62 ha and performing other analyses (hotspot analysis and near analysis), a total of 11 potential optimal waste transfer stations were selected. These optimal potential areas are shown in Figure 5 and their attribute are depicted in Table 8.

Table 6. Area extent of suitability categories.

Criteria	Less suitable (area)		Averagely suitable (area)		Highly suitable (area)	
	km^2	%	km^2	%	km^2	%
River	190.4	93.4	13.358	6.6	–	–
Settlement	118.28	58	82.711	40.6	2.769	1.4
Slope	1.046	0.5	10.178	5	192.54	94.5
Highway	85.695	42.1	37.912	18.6	80.153	39.3
Waste centre	153.65	75.4	50.11	24.6	–	–
Geology	127.08	62.4	76.684	37.6	–	–
Fault line	13.643	6.7	52.265	25.6	137.85	67.7

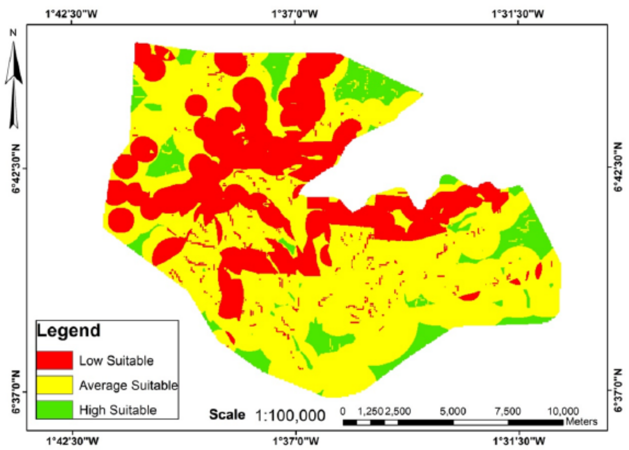

Figure 4. Suitability index map.

Table 7. Areal extent of suitability index.

Index	Suitability	Area (km^2)	Land area (%)
1	Less suitable	64.955	31.9
2	Averagely suitable	117.11	57.5
3	Highly suitable	21.695	10.6
Total area		203.76	100

Discussions

Analysis of criteria suitability

The seven criteria used in the suitability analysis were carefully selected based on literature review and in consultation with experts and decision makers. The use of rivers/streams was of great importance, as 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. A study by Mensah-Bonsu and Owusu-Mensah (2011) describes the state of water bodies in Kumasi as becoming critical, and considered the Aboabo and Subin streams dead with no aquatic life. In view of this, streams and rivers were considered one of the critical environmental concerns in this study. With a greater section of people depending on ground water in the study area, it is, however, of major importance to protect the surface water to avoid any future groundwater contamination and for sanitary reasons.

The spatial location of the Metropolis has facilitated development in all directions. 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 surroundings have become major issues with which to battle and have led to the closing down of most dumping sites within the country. This was the basis for considering distance to residential area in the site selection process. 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 waste transfer sites within an economically viable radius of collection operations is becoming increasingly essential.

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° 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. The study area had about 94.5% of land area being most suitable in terms of slope.

Proximity of a transfer station to highways was also of an importance in this study. Most of the waste transportation delays are related to the heavy traffic on the roads coupled with the bad nature of most 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. To aid access to the site by smaller trucks and to support the uninterrupted transfer of waste from the transfer station in large haulage trucks to final disposal sites, distance to highways was considered.

The result for suitability for waste generation centres shows the spatial distribution of communal container sites. Different waste collection systems cut across the study area. Some settlement areas had no communal sites at all because their waste is collected house-to-house. 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 entirely inappropriate for highly dense, congested settlements that have mushroomed on the fringes of the Metropolis. Areas within the

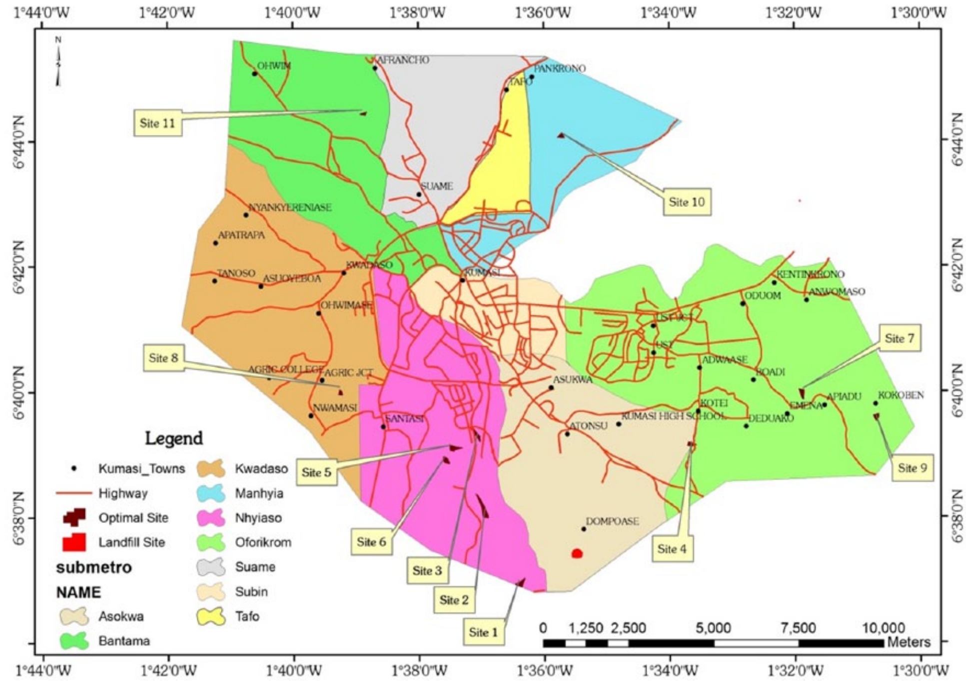

Figure 5. Maps of potential optimal waste transfer station sites.

Table 8. Area extent of the potential sites.

Site no.	Area (ha)	Distance to landfill site (km)	Rank
1	3.40	1.52	1
2	7.30	2.65	2
3	3.83	4.18	3
4	2.28	4.38	4
5	3.86	4.42	5
6	2.68	4.42	6
7	3.17	7.88	7
8	2.00	8.16	8
9	2.52	9.45	9
10	1.75	12.07	10
11	1.70	14.15	11

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.

The entire study area was characterized by two geology types, which are the Granitoid undifferentiated 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 mineral alignment, serving to destroy permeability further. Detailed study on geology 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.

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 means of conducting pollutants/contaminants into ground water.

Analysis of optimal site

The overlay of the various weighted suitability criteria maps resulted in a suitability index map from which optimal sites were obtained. The result shown in Figure 3 shows the suitability index map of the study area. Urbanized areas were rejected despite the suitability of 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. A site visit is always necessary to confirm the results of optimal sites.

Eleven optimal sites were selected; five (sites 1, 2, 3, 5 and 6) of these were located at the Nhyiaso sub metro, two (sites 7 and 9) at the Oforikrom sub metro and one each at Bantama (site 11), Kwadaso (site 8), Manhyia (site 10) and Asokwa sub metros (site 4). There were, however, no optimal sites at Suame, Tafo and Subin sub metros. The case of Subin sub metro is very important because it happens to be the most urbanized among all the sub metros and houses the central business district. The largest amount of waste happens to come from this sub metro and locating a waste transfer station would be good; however, its spatial description does not allow. One of the optimal sites (specifically site 3) in the Nhyiaso sub metro may be allocated to the Subin sub metro. However, it should be noted that the sites were ranked in relation to the clustering of waste generation centres and the location of the landfill site, and so their average distances were considered in this study. To locate waste transfer stations, economic factors that 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 narrowed down the total land area that may be considered for detailed investigation to 4 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.

Conclusions

The selection of waste transfer stations is a multifaceted process and subsequently requires that careful consideration be given to a number of environmental features of the area to be studied. This study demonstrates the use of the MCDA and GIS for site selection of waste transfer stations in KMA. The integration of MCDA and GIS provided an effective and efficient approach for identifying suitable land areas for use as waste transfer stations 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. However, it was realized that majority of the communal sites have been encroached. 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 11 optimal sites.

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 locate the best spots for transfer stations more precisely.

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References

Alanbari MA, Alanbari N, Jasim HK, et al. (2014) Modeling landfill suitability based on GIS and multicriteria decision analysis: case study in Al-Mahaweelqadaa. *Natural Science* 6: 828–851.

Barzilai J (1997) Deriving weights from pairwise comparison matrices. *Journal of Operational Research Society* 48: 1226–1232.

Boroushaki S and Malczewski J (2010) Participatory GIS: a web-based collaborative GIS and multicriteria decision analysis. *URISA* 22: 23–32.

Bovea MD, Powell JC, Gallardo A, et al. (2007) The role played by environmental factors in the integration of a transfer station in a municipal solid waste management system. *Waste Management* 27: 545–553.

Buckley JJ (1985a) Fuzzy hierarchical analysis. *Fuzzy Sets and Systems* 17: 233–247.

Buckley JJ (1985b) Ranking alternatives using fuzzy numbers. *Fuzzy Sets and Systems* 15: 21–31.

Buckley JJ, Feuring T and Hayashi Y (2001) Fuzzy hierarchical analysis revisited. *European Journal of Operational Research* 129: 48–64.

Chang SKJ, Lei H-L, Jung S-T, et al. (2008) Note on deriving weights from pairwise comparison matrices in AHP. *International Journal of Information and Management Sciences* 19: 507–517.

Crawford G and Williams C (1985) A note on the analysis of subjective judgment matrices. *Journal of Mathematical Psychology* 29: 387–405.

DeAngelo MM (2004) *Siting of Waste-to-Energy Facility in New York City Using GIS Technology*. Columbia, NY: Columbia University, pp. 1–41.

Drobne S and Lisec A (2009) Multi-attribute decision analysis in GIS: weighted linear combination and ordered weighted averaging. *Informatica* 33: 459–474.

Eastman JR, Jin W, Kyem PAK, et al. (1995) Raster procedures for multi-criteria/multi-objective decision. *Photogrammetric Engineering and Remote Sensing* 61: 539–547.

Eastman JR, Kyem PAK, Toledano J, et al. (1993) GIS and decision making. *Explorations in Geographic Information System Technology* 1.

Eminsang EF (2011) *Managing growth in Ghanaian Cities – the role of peripheral district centres*. Unpublished MSc thesis, Kwame Nkrumah University of Science and Technology, Kumasi.

Erkut E and Moran SR (1991) Locating obnoxious facilities in the public sector: an application of the hierarchy process to municipal landfill siting decisions. *Socio-Economic Planning Sciences* 25: 89–102.

Eskandari M, Homaee M and Mahmodi S (2012) An integrated multi criteria approach for landfill siting in a conflicting environmental, economical and socio-cultural area. *Waste Management* 32: 1528–1538.

Gil Y and Kellerman A (1989) *A Multicriteria Model for the Location of Solid Waste Transfer Stations: The Case of Ashdod, Israel*. Haifa: University of Haifa.

Ghana Statistical Services (GSS) (2013) 2010 Population and Housing Final Results. Ghana Statistical Services (accessed 14 March).

Hopkins L (1977) Methods for generating land suitability maps: a comparative evaluation. *Journal for American Institute of Planners* 34: 19–29.

Khan D and Samadder SR (2014) Municipal solid waste management using geographical information system aided methods: a mini review. *Waste Management & Research* 32: 1049–1062.

Kumasi Metropolitan Assemble (KMA) (2015) Kumasi Metropolitan Assembly: Working for a cleaner city. http://www.kma.gov.gh/kma/?brief-on-kma&page=5143.

Kordi M and Brandt SA (2012) Effects of increasing fuzziness on analytic hierarchy process for spatial multicriteria decision analysis. *Computers, Environment and Urban Systems* 36: 43–53.

Malczewski J (1999) *GIS and Multicriteria Decision Analysis*. New York: Wiley.

Malczewski J (2000) On the use of weighted linear combination method in GIS: common and best practical approaches. *Transactions in GIS* 4: 5–22.

Mensah-Bonsu IF and Owusu-Mensah JK (2011) State of the environment in Kumasi. *Future of the Tree Towards Growth and Development of Kumasi*. Kumasi: University Printing Press, pp. 94–174.

Nas B, Cay T, Iscan F, et al. (2009) Selection of MSW landfill site for Konya, Turkey using GIS and multi-criteria evaluation. *Environmental Monitoring and Assessment* 2010: 491–500.

Öberg H (2011) *A GIS-based Study of Sites for Decentralized Composting and Waste Sorting Stations in Kumasi, Ghana*. Swedish University of Agricultural Sciences (SLU), Uppsala.

Rafiee R, Nematolah K, Abdolrassoul SM, et al. (2011) Siting transfer station for municipal solid waste using a spatial multi-criteria analysis. *Environmental and Engineering Geoscience* 17: 143–154.

Saaty TL (1980) *The Analytic Hierarchy Process*. New York: McGraw Hill.

United State Environmental Protection Agency (USEPA) (2002) Waste transfer stations: a manual for decision making. In: Agency USEP (ed.) *Solid Waste and Emergency Response, EPA530-R-02–002*. Washington, DC: USEPA.

United State Environmental Protection Agency (USEPA) (2004) *Waste Transfer Station: A Manual for Decision-Making*. Washington, DC: USEPA.

Washburn BE (2012) Avian use of solid waste transfer stations. *Landscape and Urban Planning* 104: 388–394.

Yazdani M, Monavari SM, Monavari GA, et al. (2015) Landfill site suitability assessment by means of geographic information system analysis. *Solid Earth* 6: 945–956.

Zurbrügg C (2002) Urban solid waste management in low-income countries of asia how to cope with the garbage crisis. Presented for: Scientific Committee on Problems of the Environment (SCOPE), Durban, South Africa, pp. 1–11.