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ORIGINAL ARTICLE

Spatial Decision Support Systems for Locating Waste Landfills

***Olayinka Waziri Otun**

Department of Geography, Olabisi Onabanjo University, PMB 2002, Ago-Iwoye, Ogun State, Nigeria

*Corresponding author: otunwo@yahoo.com

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Abstract

The decision process to locate an undesirable facility like a waste landfill usually involves many stakeholders and many location criteria. The views of the stakeholders on the importance of the criteria often differ. Such a location problem is termed 'a complex spatial problem' and is solved by spatial multi-criteria based approaches. The objective of this paper is to provide a spatial decision support system (SDSS) that integrates multi-criteria and location-allocation (L-A) models to support the decision process of locating a waste landfill. The SDSS was applied to find a suitable location for a landfill in Ijebu-Ode, a medium sized city in Nigeria. The data input into the multi-criteria analysis model of the SDSS include three town planning regulatory constraint maps and four environmental factor maps. Data input into the L-A model include the location and amount of waste generated at nineteen waste collection points in the study area. Data on the road network was used to determine movements between the waste collection points and the landfill. To determine the most suitable area for the landfill, the factor maps were weighted by the stakeholders' preferences and combined with the constraint maps to eliminate areas that cannot be used for the landfill. The result of the map combination and weighted overlay procedure, resulted into twenty seven environmentally suitable areas. To find the most efficient of the twenty seven suitable locations, the L-A model was applied. The chosen facility location is the most efficient for the waste management system in terms of transportation cost. The usefulness of SDSSs as a decision support tool in solving complex spatial problem has been demonstrated in this paper. Improvements in available data and existing GIS can encourage similar systems to be designed and used by decision makers, particularly in developing countries.

Keywords: Complex spatial problem; landfills; multi-criteria analysis; location-allocation model; SDSS.

Introduction

Finding an appropriate location for human activities is quite an intellectual challenge, but it is a very important problem from the practical point of view, for there are many obvious and immediate applications with very strong humanitarian overtones (Abler, Adams and Gould, 1971).Traditional location theories are usually based on a single objective of maximizing some economic benefits or minimizing some costs. However, later development leads to the need for and the development of multi-criteria location decision models. The factors that lead to the development of multi-criteria models include the increasing complexity of the environment in which location decision takes place. Apart from the economic factors, the issue of social justice as well as concern for the environment is fundamental in location decision process in recent times. In addition, planning regulations are also taken into cognizance in location decision making (Mendes, 1997). Complex spatial problems often have multiple, conflicting objectives and are ill- or semi-structured. Decision makers faced with a complex spatial problem often have multiple, conflicting objectives for its solution. To be acceptable, a solution must reconcile these conflicting goals (Densham, 1991).

Decision makers are increasingly turning to GIS to assist them with solving complex spatial problems. GIS has been recognized as a useful tool in siting experiences (Ferretti, 2011) and Higgs (2006) highlighted the potential of integrating multi-criteria techniques with GIS in waste facility location. GIS has been widely used to lower the cost of the selection process of sites for various purposes (Sharifi and Retsios, 2004). However, Sharifi, et al. (2009) identified that it lacks the ability to locate an optimal site unless an optimization arrangement is introduced. GIS do not adequately support decision making because they are lacking in analytical modeling capabilities and do not easily accommodate variations in either the context or the process of spatial decision making (Densham and Rushton, 1988; Goodchild, 1989; Harris and Betty,1991). One response to these shortcomings is the development of spatial decision support systems (SDSS) which are explicitly designed to address complex spatial problems. SDSS can provide a problem solving environment which is flexible and will allow the decision maker to explore the problem (Jankowski,1995). Densham (1991) pointed out that the characteristics of Decision Support System (DSS), developed in management sciences, can be used to define SDSS. The characteristics of SDSS have been vastly discussed in the literature (Keen, 1980; Densham, 1991, 1994; Wright and Buehler, 1993; Turban and Aronson, 2001; Ayeni, 2010). These characteristics include: support for the capture of spatial and non-spatial data, a flexible architecture, methods peculiar to spatial analysis, ability to generate a variety of outputs, an integrated interface, an architecture that supports the addition of new capabilities, etc. SDSSs have been regarded as GIS in some quarters, but they are not GIS. SDSS have an edge over conventional GIS in that they incorporate a greater level of analytic and statistical modeling which is required to assist the process of decision making (Ayeni, 2010; Armstrong et al, 1991).

It has been recognized that the selection of the appropriate landfill site can be viewed as a complex spatial problem that requires an extensive evaluation process (Geneletti, 2010). Apart from the technical suitability and economic criteria, the political context of the decision making process requires taking social and environmental criteria into account. These criteria are sometimes conflicting. For example, the residents will not want the waste landfill, close to the residential areas, and the waste managers will want a landfill whose location will not be too far from the waste generating areas. There are many multicriteria methods to resolve decision making problems involving conflicting criteria. Norese (2006) and Queiruga et al. (2008) used multi-criteria decision analysis methods to resolve conflicting criteria problem in siting waste landfills. Khan and Faisal, (2008) and Ferretti (2011) specifically used analytic network process (ANP), a multi-criteria method, to examine the sustainability of the decision process of locating municipal landfills. As landfills are usually operated for many years, there is need to harmonize the consideration of environmental/ safety factors and the efficiency of the operations, while deciding the location of a landfill. Most previous studies focused on the efficiency of the location of a landfill, in terms of operating routes from the waste pick up points to the landfills (Truitt, et al., 1969; Aremu, et al., 2011), while others focused on methods of finding suitable locations for landfills (Ferretti, 2011; Suman, 2012). The SDSS discussed in this paper integrates the two approaches. The aim of this paper is to provide a spatial decision support framework that can support multi-criteria decision making in site selection for a waste landfill. The framework integrates basic GIS functions, multi-criteria decision model and location-allocation model.

The application of the SDSS to a landfill location problem in Ijebu-Ode, a medium sized city in Ogun state, Nigeria, is presented in this paper. The study area consists of Ijebu Ode metropolitan area and the immediate area around the city. Areas immediately outside the metropolis are considered as part of the study area as landfills are not usually allowed within or close to human settlements. The study area lies between longitude 30 52’ 26’’ and 40 00’ 10’’ East of the Greenwich Meridian; and latitude 60 47’ 2’’ and 60 52’ 48’’ North of the Equator. Ijebu-Ode metropolis is the second largest urban centre in Ogun state, next to Abeokuta, the state capital. The 2016 projected population size of the city is 273,343 (Ogun State Government, 2010). Topographically, Ijebu-Ode presents a generally gently undulating plain, which rises from about 20meters above sea level. The topography is underlain by young sedimentary rocks (Jurassic-Cretaceous) (Onakomaiya, et al, 2000).

Wastes generated by households in Ijebu Ode are collected by trucks that move around the city, to collect wastes which are taken to the landfill close to a settlement called Ikoto (see Fig.1 for map of the study area and the existing landfill). The landfill at Ikoto is currently posing hazards to the immediate community. Ikoto has expanded in the direction of the landfill, which is very close to a major highway from Sagamu to Benin. There is a case at the judiciary court, by the residents of Ikoto against the government owned waste agency, that the existing landfill constitutes a nuisance to them. Thus, the waste agency is taking steps to find another suitable area for the landfill.

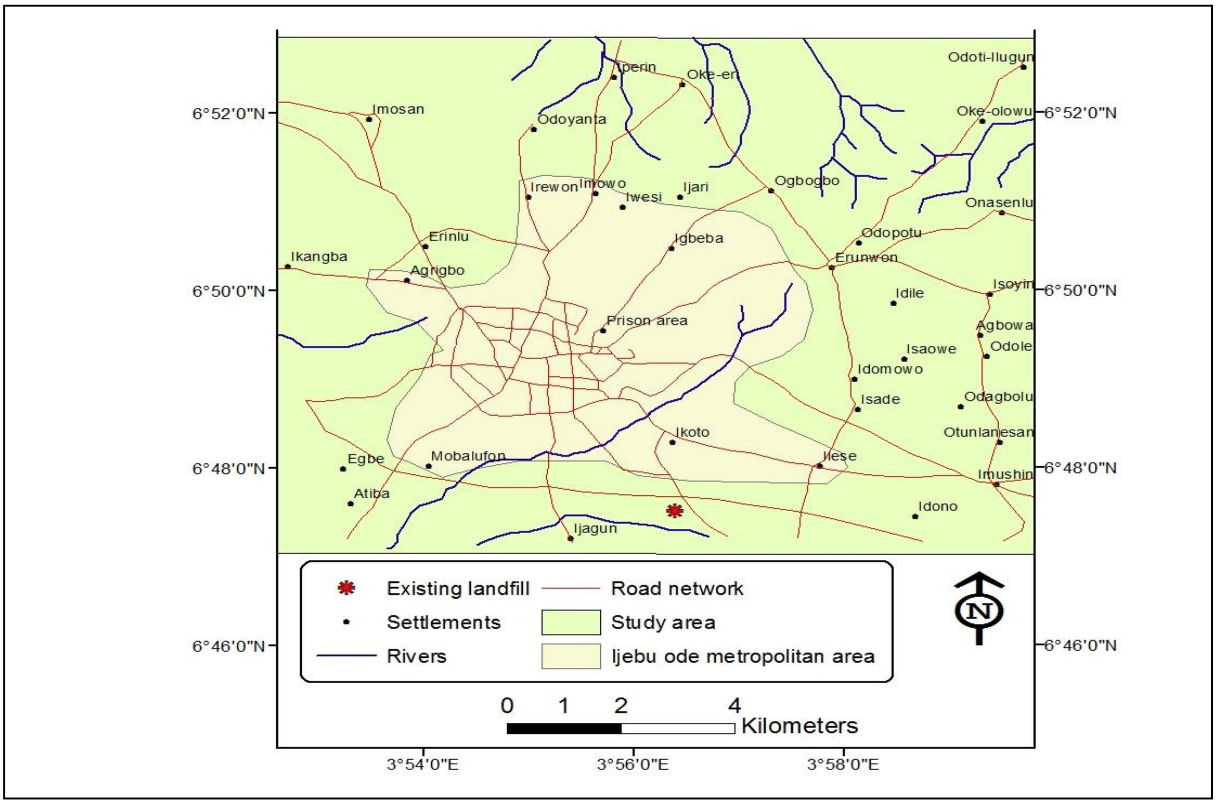


Figure 1. Ijebu Ode and Environs

Methodology

This paper discusses the design and application of a SDSS to support the decision process of locating a waste landfill in a city. SDSSs are typically made of three components: the dialog or interface, the data and the models. The interface aids the user’s interaction with the SDSS. The user enters data and get results from the SDSS through the interface. The data component handles the spatial and non-spatial data. The geographic information system (GIS) is increasingly being used today to handle spatial and non-spatial data for SDSSs. The third component is the library of models whose outcomes are to aid decision making. The models are core part of SDSSs (see Fig. 2 for relationship between the components of the SDSS). The dialog component of the SDSS in this study uses the interface of ArcGISv10, a GIS software by ESRI Inc. The spatial data for the SDSS consist of maps showing the distribution of relevant factors and the non-spatial data are the information from the relevant stakeholders on their preferences for the different factors. The model component of the SDSS consists of the Analytic Hierarchy Process (AHP) and location-allocation models. The GIS and AHP are used to generate suitable areas for the landfill, while the L-A model is used to find a final optimal site out of the generated suitable areas.

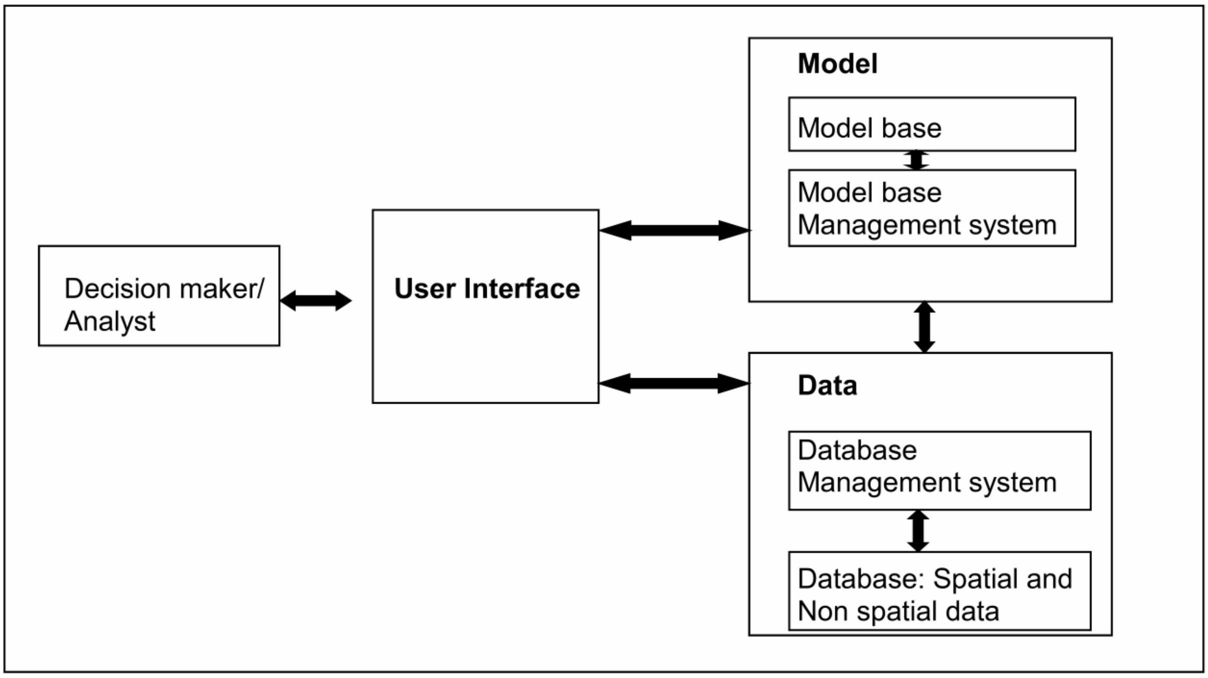


Figure 2. A Typical SDSS Framework

The Data for the Study

The data input into the multi-criteria waste landfill location model are categorized into three: the constraints, the factors and the decision makers' weights for the criteria. The constraints are maps of the study area, showing areas that are marked as unsuitable for the location of the landfill. The constraints are set according to environmental standards and town planning regulations. The constraints to locating landfills observed in this paper are: 50 metre setback from roads, 150 metre buffer around surface water and 500 metre distance from settlements. The details of sources and measurements on the constraint maps are shown in Table 1.The factor or criterion maps show the distribution of the criteria used in determining a suitable location for the landfill. Maps are prepared for the following factors in this paper: ground water depth, distance to road, distance to existing landfill, land use type, land value and slope. The details of sources and measurements of the factor maps are contained in Table 1.

The identified stakeholders involved in the decision process of locating waste landfill in this study are, the environmental sanitation office, the town planning office and a non-governmental organization (representing the people). Preliminary interview with the environmental sanitation officer and town planner shows that they attach different levels of importance to the location criteria. Thus the AHP method by Saaty was used to elicit weights for the criteria from the three stakeholders. The stakeholders could not be organized in a focus group for the weight assessment. They were visited with assessment forms on which they perform the pair wise comparison of the criteria. The results of the weight assessment are discussed in the section on model application.

Data for location allocation modeling include the demand points, the candidate locations and the transport network. The demand points are the waste collection points and are weighted by the amount of waste generated from each point. The candidate locations are the most suitable areas for siting the landfill as identified by the application of the multi-criteria decision model. The transport networks of the study area are used for determining the pattern of interaction in location-allocation modeling.

Table 1. Maps Used to Represent the Criteria

Criteria	Map Used	Reason for Criterion	Measurement
		Constraints	
Setback from roads	Nigeria Topo-sheet 280 N.E, 1:50,000	Planning regulation on road setback	Road setback. Distance less than 50m (Oliet, et al. 1993) is set to 0, all other areas are set to 1
Surface water protection	Nigeria Topo-sheet 280 N.E, 1:50,000	Planning regulation on protection of surface water	Buffer around surface water. Distance less than 150m (Ferretti, 2011) to rivers and surface water is set to 0 , all other areas are set to 1
Distance from settlements	Nigeria Topo-sheet 280 N.E, 1:50,000	Regulation to reduce pollution impact to public health	Distance less than 500m is set to 0, all other areas are set to 1-Oliet et al., 1993)
		Factors	
Ground water depth	Map of ground water depth[a]	Regulation to prevent pollution of ground water	The higher the ground water depth the higher the score
Distance to road	Nigeria Topo-sheet 280 N.E, 1:50,000	Closeness to existing roads to save transport cost	Landfills should be near the roads to reduce the cost of operation (Lindquist, 1991). The higher the distance the lower the score
Distance to existing landfill	Nigeria Topo-sheet 280 N.E, 1:50,000	To reduce impact to public health	Distance to existing landfill. The higher the distance the higher the score
Land use	Land use map[b]	To know the effect on the present and future land use patterns after placement	The land in the area is classified into four classes. The higher the natural value the lower the score
Land value	Real estate values[c]	To determine effect on value of adjoining lands	The higher the real estate values, the lower the score
Slope	Digital elevation model (DEM)[d]	Slopes are derived from the DEM	A low slope is required for landfills (Kao*et al* (1997). The higher the slope the lower the score

[a] Ground water depth data obtained from Geology Dept. Olabisi Onabanjo University, Ago-Iwoye, Ogun State, Nigeria
[b] Landsat Imagery from GLCF
[c] Land-value data from Jide Taiwo & co. (Estate Firm)
[d] Shuttle Radar Thematic Mapper (SRTM, 90m).

Data on the location of waste collection points and truck loads of waste that were collected from each point was collected from the government waste agency in Ijebu Ode. Nineteen waste collection points were identified within Ijebu Ode metropolitan area. The government waste collector agency moves round the city with trucks to collect wastes which are taken to the landfill. The network dataset for location-allocation modeling in ArcGIS include the digitized road networks and junctions in the study area.

Analytical Methods

The model component of the SDSS consist of multiple criteria decision making (MCDM) model and the location-allocation (L-A) model. The MCDM model uses the GIS functionality in ArcGIS v10 to determine the suitability of the pixels making up the area based on their criterion scores. As part of the multi-criteria decision modeling, the stakeholder's preferences were articulated and used to weigh the criterion maps. The Analytical Hierarchy Process (AHP) was used to articulate the stakeholder's preferences. The L-A model was used to find the location, out of the suitable areas, that yields the minimum transport cost from the waste generating points. The features of the MCDM and L-A models are outlined below. MCDM models are used to solve spatial decision problems with large sets of feasible alternatives and multiple conflicting and incommensurate evaluation criteria. MCDM approaches allow for flexible integration of the attribute/spatial data and decision maker preferences. (Ascough, et al. 1999). In recent years, research and development of SDSS has expanded to include multi-criteria analysis (Malczewski, 1999; Feick and Hall, 2004; Ferretti, 2011). One popular multi-criteria method that has been used in waste landfill location problem is the analytical hierarchy process (AHP) (Ferretti, 2011; Padmaja, et. al. 2006). The AHP was developed by Saaty (1980). It allows the use of qualitative, as well as quantitative criteria in evaluation..

The general steps in AHP algorithm are outlined below:

- Information is decomposed into a hierarchy of alternatives and criteria
- Pairwise comparisons of criteria and alternatives are made with the grades ranging from 1-9
- These pairwise comparisons are carried out for all criteria/ alternatives to be considered, usually not more than 7, and the pairwise comparison matrix is completed.
- The Eigen vector X (priority vector) which gives the priorities of the criteria/alternatives is computed.

Location-allocation (L-A) model is the second model used in this study. It is to find the location for the landfill that will yield the minimum operating transport cost. The p-median version of the L-A model finds the locations of p facilities to minimize the demand-weighted total distance between demand nodes and the facilities to which they are assigned. The model is formulated as follows (Ayeni, 1992):

$$\textit{Minimize } \sum_{i \in I} \sum_{j \in J} h_i d_{ij} y_{ij} \text{ (the objective function)} \quad (1)$$

$$\textit{Subject to}:$$

$$\sum_{j \in J} x_j = p \quad (2)$$

$$\sum_{j \in J} y_{ij} = 1 \forall i \in I \quad (3)$$

$$y_{ij} - x_j \leq 0 \forall i \in I, j \in J \quad (4)$$

$$x_j \in \{0,1\} \forall j \in J \quad (5)$$

$$y_{ij} \in \{0,1\} \forall i \in I, j \in J \quad (6)$$

The objective function minimizes the demand-weighted total distance, where:
I = the set of demand nodes indexed by i
J = the set of landfill locations, indexed by j
d_{ij} distance between demand node i and landfill site j
h_i = demand at node i
p = the number of landfills to locate

$$x_j = \begin{cases} 1 \; if \; we \; locate \; at \; site \; j \\ 0 \; if \; not \end{cases}$$

$$y_{ij} = \begin{cases} 1 \; if \; demand \; node \; is \; assigned \; to \; a \; landfill \; at \; node \; j \\ 0 \; if \; not \end{cases}$$

The objective function (1) minimizes the demand-weighted total distance travelled. Constraint (2) stipulates that p facilities (landfills) are to be located. Constraint set (3) requires that each demand node be assigned to exactly one facility. Constraint set (4) restricts demand node assignments only to open facilities. Constraint set (5) established the siting decision variable as binary. Constraint set (6) requires the demand at a node to be assigned to one facility only.

Results

Application of the SDSS to the Case Study

The SDSS outlined above has been applied to the case of locating a waste landfill in Ijebu-ode, a medium sized city in Nigeria. The framework by Simon (1960) was adopted in structuring the decision process discussed in this paper. The decision framework divides the decision making process into three phases: intelligence, design and choice. Outline of activities at the different phases are shown in Table 2.

Table 2: Phases of the decision process

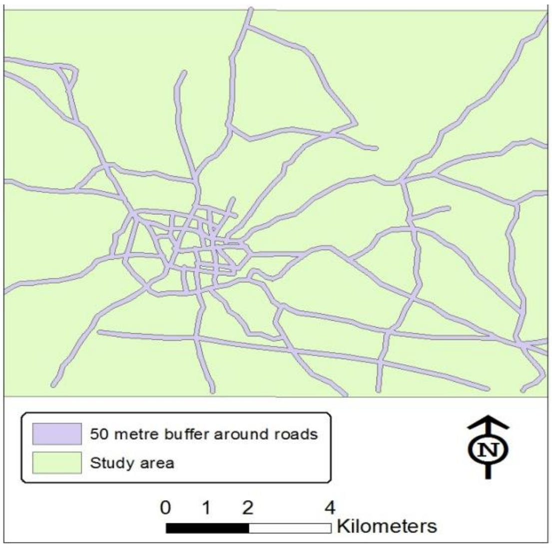
Phases	Activities
Intelligence	1. Statement of problem
	2. Data acquisition and processing
Design	3. Standardising evaluation criteria
	4. Criteria weighting
	5. Results aggregation
Choice	6. Recommendation/ selection of a particular alternative

Intelligence Phase

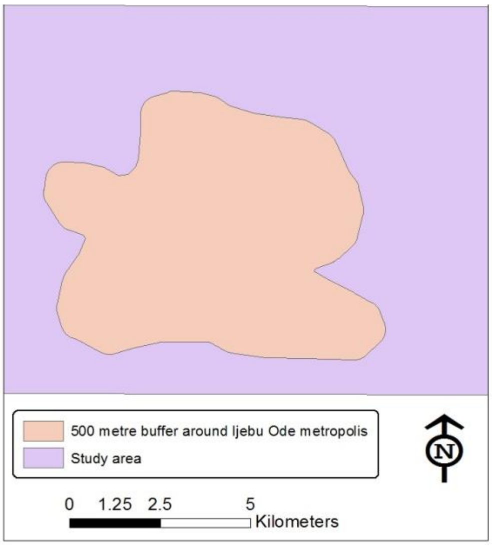
The problem is to find the most suitable location for a waste landfill. The problem is a complex land use planning problem, given the many criteria to be considered and many stakeholders that are involved in the decision process. The criteria considered while seeking for a suitable site for landfill are related to safety of the environment and the public and the economy of operation of the landfill. For example landfill site should be kept as far as possible away from densely populated areas, to reduce pollution impacts to public health. On the other hand they should not be too far from waste generating centers to save transportation cost.

Criteria considered in locating a landfill usually border on environmental, socio-economic, political and regulatory issues. In this paper ten criteria were considered in the computation process. They consist of four constraints and six factors. The set of criteria was selected from relevant literature and on the requirements of town planning regulations relating to location of landfills. The literature and legislations backing the chosen criteria for the landfill problem are provided in Table 1. Constraints determine which areas should be excluded from or included in the suitability analysis (Noble, 1992; Ferretti, 2011). The constraints are turned into Boolean maps with a value of zero for areas to be excluded and one for areas that are feasible for landfill location. In this study areas to be excluded are: 50-metres distance from the roads, 150-metres buffer around surface water, 500-metre buffer around existing settlements (see Fig. 3).

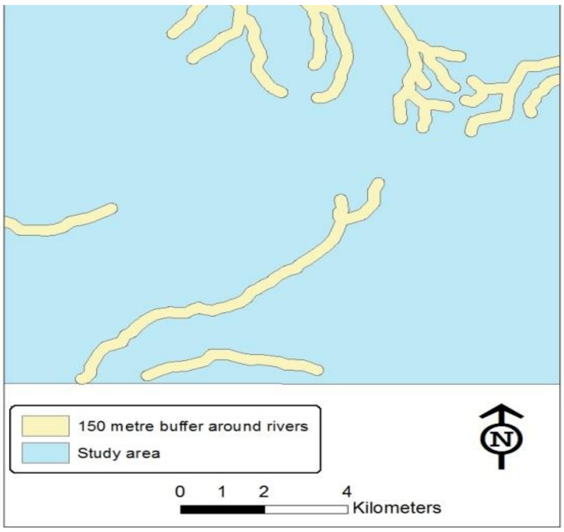
The overall constraint map was calculated by multiplying all the constraint maps using map algebra tools such that any area that do not satisfy any of the constraints are mapped as excluded from the analysis. Sources of the constraint maps are shown table 1. The constraints are to implements town planning and environmental safety regulations for landfill location. The factors considered in this study are: ground water depth, distance to road, distance to existing landfill, land use type, land value and slope. Fig. 4 contains maps showing the distribution of the factors in the study area. Raster maps were produced for each of the source factor maps. The source and derived raster maps as well as the reason for their inclusion are shown in Table1. One criterion that is common in previous studies and is not used here is the soil type. The soil distribution in the area is homogeneous. It is mainly laterite soil type (Adeyemi and Ogundero, 2001).



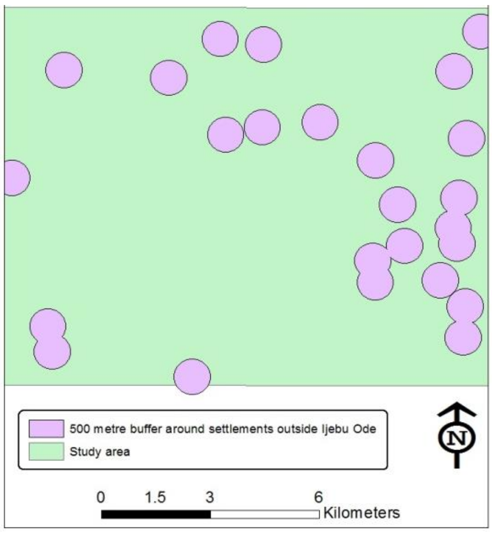
50 metre buffer around roads



500 metre buffer around Ijebu-Ode metropolis

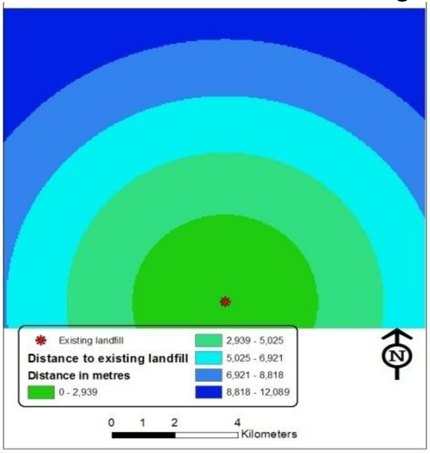


150 metre buffer around rivers

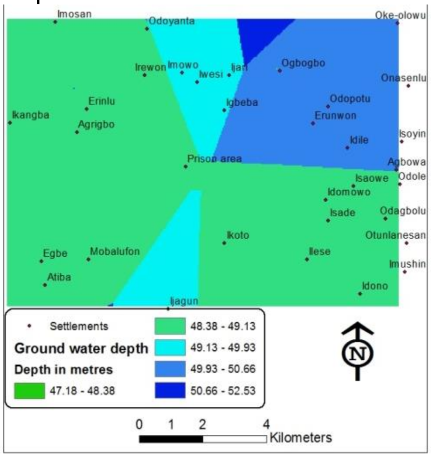


500 metre buffer around settlements surrounding Ijebu Ode

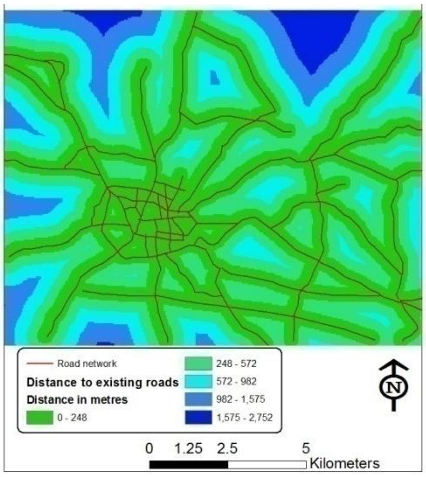
Figure 3. Constraint maps



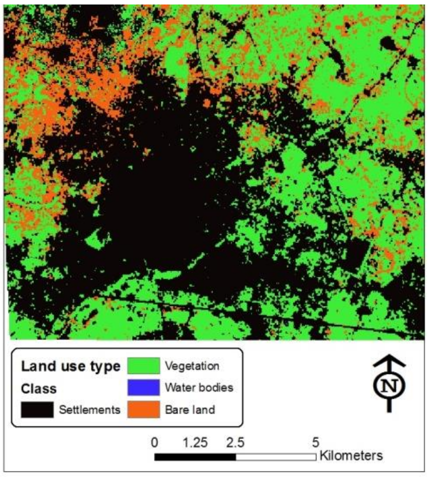
Distance to existing landfill



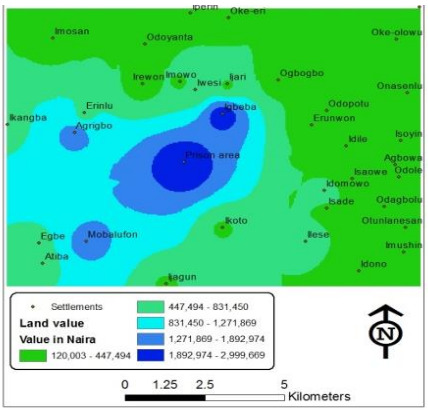
Map of ground water depth



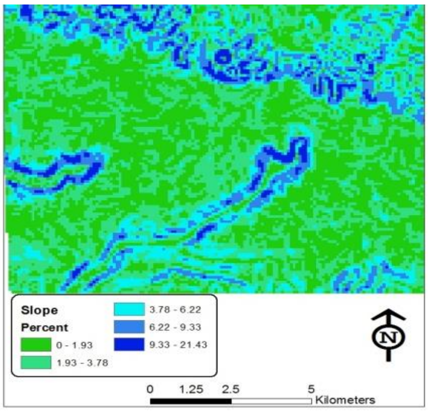
Distance to existing roads



Land use map



Land value map



Slope map

Figure 4. Factor maps

Design Phase

The design phase of the decision process involves standardization of the criteria, weighting of the criteria by the stakeholder's preferences and aggregation of the weighted maps, to arrive at a composite or suitability map for landfill location. Some of the created maps are classified maps, like the land use map which shows settlement, vegetation, water body, etc. Other maps are value maps, like the slope map which shows slopes in percentages. For decision analysis, the values and classes of all the maps are converted into a common scale (Voogd, 1983; Ferretti, 2011). The data set are thus, standardized by converting to a common measurement scale to make them to be comparable. A range of 1 – 10 was used in this study for all the maps. A pixel on the map with score of 1 = 'least suitable' and a pixel with a score of 10 = 'most suitable'. The 'reclassify' tool of ArcGIS was used to standardize or reclassify the maps from old values to new suitability scores. The factor maps used in the study are shown in Fig. 4.

If all factors were equally important, there will be no need to weigh them. Factors do not usually have the same importance, according to the stakeholders involved in the decision process. The importance level is obtained by assigning weight to each factor and is included in the evaluation. The weights are means of including the decision makers and stakeholders' viewpoints into the landfill location decision analysis. The Analytical Hierarchy Process (AHP) is used in this study to derive factor/criteria weights based on the preference information from the stakeholders. It is a well-known weight assessment technique developed by Saaty (1980). The AHP analysis carried out in this study was done using a simple designed spread sheet (Microsoft Excel) model.

In this study, the participants/stakeholders include an environmental sanitation officer, a town planner and an officer from a non-governmental organization (JDPC). The pairwise comparison of the factors by the stakeholders, were obtained through an assessment form designed for them. The consistency of the pairwise comparison by each stakeholder was checked by calculating the consistency ratio (CR). According to Saaty (1980), the CR should be less than 0.1, otherwise the comparison should be revised in order to improve the measurement accuracy. None of the CR computed for the pairwise comparison by the stakeholders in this study was greater than 0.1. The geometric mean of the criteria weights generated by the stakeholders for each factor is taken as the weight for that factor.

The last step of the design phase is the aggregation of the constraint maps, standardized factor maps and stakeholder's factor weights. The standardized factor maps are weighted by stakeholder's weights and combined with the constraint maps to obtain the overall suitability map. Each factor map was multiplied by its respective weight (i.e. the geometric mean of weights by the three stakeholders). The weighted factor maps were summed to derive a weighted composite factor map, using the 'weighted overlay' tool of ArcGIS. The overall constraint map was multiplied by the weighted composite factor map to mask unsuitable areas, which are excluded from the analysis. The 'map algebra' tool of ArcGIS was used for multiplying the maps. The final suitability map is thus derived. The final suitability map shows the attractiveness of each pixel in the study area in the scale between 1 (the least suitable area) and 10 (the most suitable area). Fig. 5 shows the suitability of the study area for waste landfill location. None of the pixels has the maximum suitability score of 10 due to the compensatory aggregation approach used, and areas with suitability score below 4 have been masked by the constraints.

In this study, the objective is that, apart from the suitable areas, meeting the environmental, safety and planning conditions, they are to have a minimum size of ten hectares. This size is derived from available landfills in nearby Lagos metropolis. Lagos metropolitan area has three landfills: Olushosun (42.7 hectares), Igando (7.8 hectares) and Abule Egba (10.2 hectares)(Longe and Balogun, 2010). Ijebu Ode population is not as fast growing as Lagos, thus it is proposed that a ten hectare landfill will be adequate. The following steps are taken to determine the suitable areas that meet the minimum threshold size for the landfill. All the procedures were carried out in ArcGIS:

i. the 'con' tool in ArcGIS was used to extract and map the most suitable areas. For example, the conditional expression 'value >= 9' make all cells with a suitability value of 9 to retain their value while all other areas are changed to 'NoData';
ii. isolated and small areas on the extracted map are removed by applying the 'Majority Filter' tool leaving the filtered optimal areas;

iii. the filtered optimal areas are converted from raster to vector format using the 'raster to polygon' conversion tool; and
iv. the 'select by attribute' tool is used to select suitable areas in vector format (areas greater than or equal to ten hectares were selected).

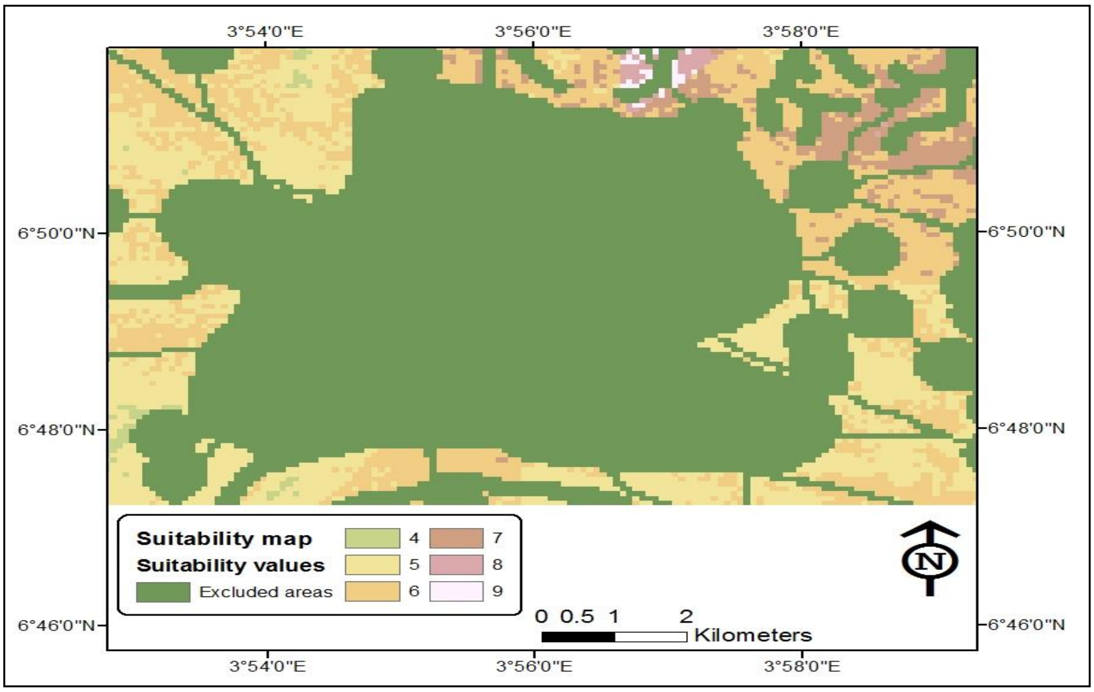


Figure 5. Suitability of the study area for waste landfill location

The application of the outlined steps above to the map showing only areas with suitability score of 9 indicates that none of the areas is up to the required ten hectares. Thus, a sort of 'what-if-analysis' was carried out and the result shown in Table 3. For example, suitability map showing areas with suitability score that is greater than or equal to7 has seven areas that is greater than or equal to ten hectares. The seven areas are clustered around the same area and this will not allow for the consideration of efficiency in location of the landfill while considering the daily operation of the waste managers. Thus, a suitability map, showing areas with suitability score greater than or equal to 6, has 27 areas whose sizes are greater than or equal to ten hectares and are spread over the study area. The identified 27 sites were the prospective candidate sites in the location-allocation modeling discussed in the next section.

Table 3. Level of Suitability and Discrete Areas Meeting the Minimum Threshold for Landfills

Suitability Map	Discrete Areas on the Map with Size Greater than Ten Hectares
Having suitability level that is greater than or equal to 9	None
Having suitability level that is greater than or equal to 8	1
Having suitability level that is greater than or equal to 7	7
Having suitability level that is greater than or equal to 6	27

The Choice Phase

The choice phase of the landfill location decision process involves the use of the location-allocation model to determine one out of the 27 identified environmentally suitable sites for the landfill. The 27 candidate sites are polygons of different shapes and their centers are needed for L-A modeling. The ArcGIS 'feature to point' tool was used to find their centers. The chosen location out of the 27 will minimize the weighted distances from all the waste collection points and thus, be the most efficient in terms of transporting costs. The distances are weighted by the truckloads of waste from the collection points.

The p-median option of the location-allocation model was used to find the optimal pattern of allocating the nineteen waste collection centers within Ijebu Ode metropolis to one of the 27 potential sites for the landfill. The most efficient location out of the 27candidate sites generated by the multi-criteria model is shown in Fig. 6. The spider lines connect the waste generating centers to the selected location for the landfill. The allocation modeling has been computed based on interaction through the actual transport networks in the study area. The spider lines that depict direct connection between the waste generating points and the chosen location are for illustrative purpose.

Discussion

The SDSS described in this paper is to support the decision to locate a landfill to serve a city. The designed SDSS can be expanded and adapted to support the decision of where to locate a transfer station between the waste generation centers and the landfill. The SDSS has been applied to locating a waste landfill in this paper, but the framework of the SDSS can actually be adapted to support location of other undesirable facilities. Such facilities usually exhibit similar location characteristics. The SDSS is usually prototype systems to be developed to focus on a sub-problem, and tailored to be more fully functional (Bailey, 2005). The interface and data base management system (DBMS) of ArcGIS v 10 were used in the design of the SDSS in this paper. The ArcGIS provided comprehensive location characteristics. The SDSS is usually prototype systems to be developed to focus on a sub-problem, and tailored and robust interface.

Environmental factors, safety, planning regulations were taken into consideration as determinants of the location of a landfill in the design of the SDSS in this paper. Economy or efficiency of operation has also been considered. Landfills are usually operated for years and as such, methods to minimize the daily transport cost of moving the waste must be considered in the design of a decision support system. This study has also factored in the size of the site into the analysis by allowing only areas that are up to a minimum threshold size to be considered in the location decision process. The design of SDSS are to be simple in concept so that the decision makers can understand how the system works, accept their output and not see them as black-boxes (Bailey, 2005).The constraint and factor maps in the SDSS, in this paper, are simple enough for an average person to understand. Also, the principles behind allocating the waste generating points to an efficient landfill location site using the L-A model is not ambiguous.

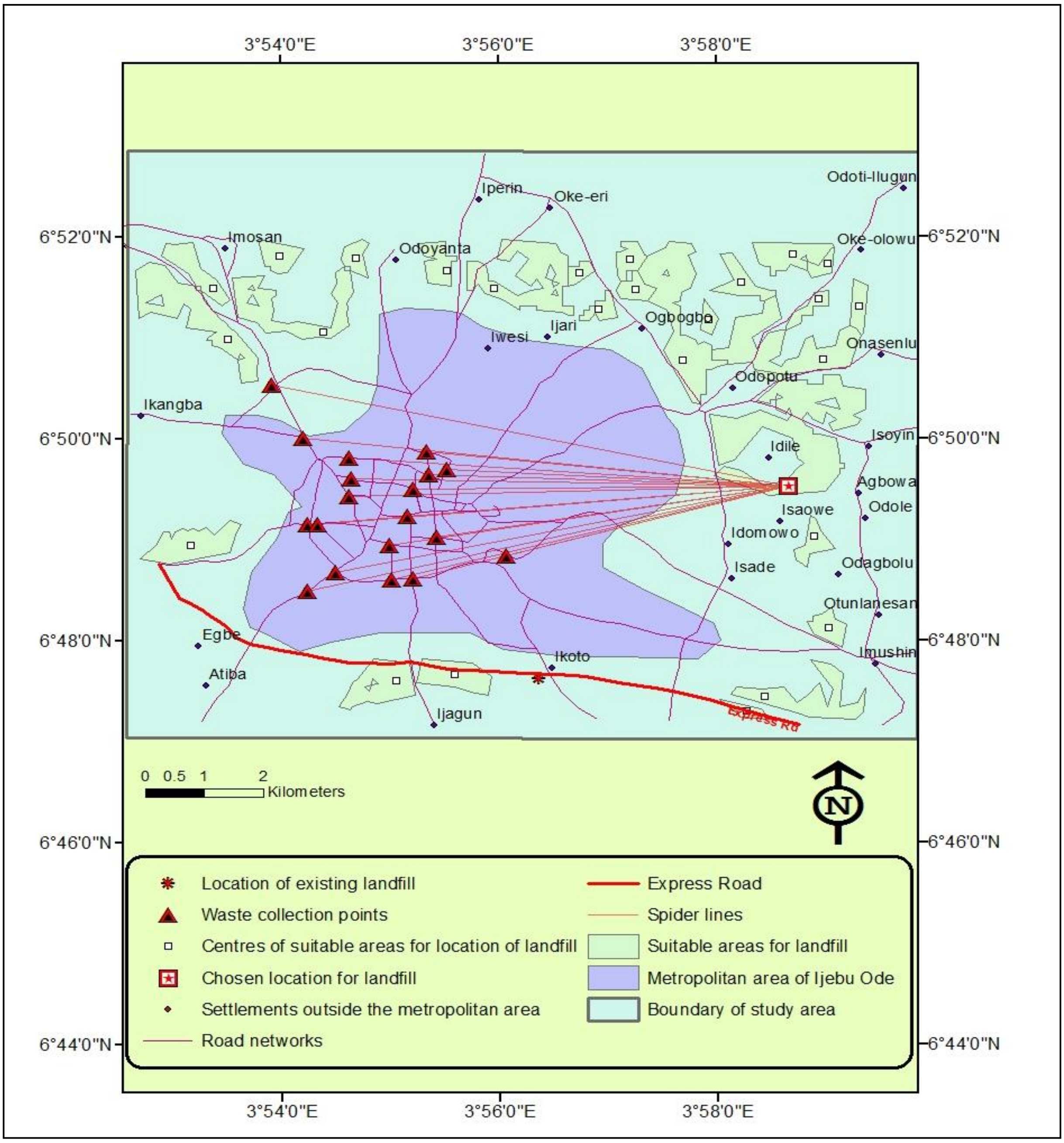


Figure 6. Optimal solution to the landfill location problem

Conclusion

This paper has demonstrated the application of SDSS to a real life problem and has pointed to the possibility of using such a planning tool in developing countries. Thus, it is recommended that more researches be conducted to develop similar tools. For example waste transfer stations are just emerging as part of the waste management system in developing countries and there is need to develop decision support tools that can aid policy makers in determining appropriate location for them. The location of such transfer station must have minimal impact on the environment and at the same time must be operationally efficient. However to develop decision support tools for policy making in developing countries will require improvements in available data and the analytic capability of existing GIS.

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