Site selection model for urban solid waste disposal management using GIS and remote sensing: a case of Gulu Municipality

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Site selection model for urban solid waste disposal management using GIS and remote sensing: a case of Gulu Municipality

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Abstract: The management of solid waste disposal is an issue that features in urban planning due to population rise and hence build-up of solid wastes. Planners are forced to use suitable disposal means to minimise damages that may occur to ecosystem and population. This study sought to develop a site selection model for urban solid waste disposal management. The aim of the study was attained by assessing the current system of: waste collection; transportation; disposal and monitoring to identify model requirements before its design and validation in Gulu Municipality. A total of 370 respondents were purposively sampled using Morgan table for sample size and managed with the help of questionnaires and interviews. The methods of: GIS and remote sensing; spatial multi criteria evaluation and analytical hierarchy processing were used in the study. The determined damping sites were classified by aggregation based on criteria weights and the best one selected using a sizing procedure.

Keywords: model; site selection; waste disposal; geographic information system; GIS; remote sensing; urban; Gulu Municipality.

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1 Background to the study

Solid waste management is a great global concern due to various challenges associated with it. Solid waste collection and management are the most critical issues that dominant the process of planning in urban and the improper management of solid wastes leads to diseases, fire hazards, bad odour and pollution of air and water (Mujibor et al., 2008). The challenge of managing solid wastes is severe in developing countries such as Uganda (Okot-Okumu and Nyenje, 2011). This is one of the immediate problems that confront the concerned authorities. The concerned authorities are faced with a lot of difficulties in relation to solid waste collection and damping. One of the difficulties is lack of finance to handle the huge amount of solid wastes that are produced by the inhabitants of urban setting coupled with the use of old ad hoc method of collection, transportation and damping. The current solid waste disposal method is still inefficient and inadequate as well as lacks criteria for selecting the most suitable sites.

Padmapriya et al. (2014) note that the conventional disposal of solid wastes lacks: information about the collecting time and area; proper monitoring and tracking of bin status. The conventional approach uses many trucks to collect garbage and transfer solid wastes to a location without monitoring and control.

A proper solid waste management is vital for a healthy environment. Despite the limited number of studies that have been carried out in this area, an effective and robust innovative approach is still needed to boost the efficiency of managing urban solid wastes. One of such innovative approach is to use information technology (IT) such as geographic information system (GIS) and remote sensing (RS) techniques that are now available to bridge the gap (Latifah et al., 2009).

The advance of IT such as GIS and RS has provided extensive processed data from the surface of earth. Most of the information is organised in computer systems and the rest either free or accessed at low cost. Research in disciplinary sciences has also produced insight into many physical and socio-economic processes. Yet much of the existing information and knowledge is not used to support better management of resources. Geo-information technology has offered appropriate technology for data collection from the surface of earth. But GIS lacks a well-developed analytical capability to support the process of making decisions. GIS and RS have also been used in a number of areas such as global management of wastes (Rolf et al., 2001; Oindo and Skidmore, 2003; Sugumaran, 2003; Margarida, 2005; Nakakawa, 2006).

GIS is a special type of decision support system (DSS) that deals with analysis of geospatial data and creates prospects for a number of organisations and individuals (Hendriks and Dirk, 2001; Rolf et al., 2001). Many organisations, both private and public need GIS to support their decisions based on geo-references. According to Open GIS Consortium (OGC, 2006), programs of the community and government can be supported with the help of GIS techniques.

This study sought to develop a site selection model (SSM) for managing urban solid waste disposal by using GIS and RS. To achieve the aim, we determined requirements to design and validate the proposed site selection model. SSM is envisaged to guide urban solid waste disposal management apart from adding to the knowledge by extending the related models. SSM is also an informative model for boosting community health and future research.

1.1 Solid waste management theories, models and techniques

This study has been underpinned by a number of theories, models and techniques of solid waste management. The concepts of Shafiul and Mansoor (2004) and Pongrácz et al. (2004) provide the basis of managing solid wastes in a setting or country. Pongrácz et al. (2004) points out that:

> "The theory of waste management is a unified body of knowledge about waste and waste management, and it is founded on the expectation that waste management is to prevent waste to cause harm to human health and the environment and promote resource use optimization."

1.1.1 Logistic management and spatial planning model

Logistic management and spatial planning model (LMSPM) by Ogra (2003) was developed to manage solid wastes with the help of GIS in the City of Dehradun where the conditions of disposal bins were alarming with garbage lying outside or around them. In this situation, apart from the inconvenience caused to the citizens it also made waste collectors to do their work improperly. The model indorsed the upkeep of inventory so that the data of employees in the waste management is made available to analyse if their numbers are sufficient to handle the given work. The LMSPM uses ArcGIS and ArcMap among other tools to obtain required information or new layers. LMSPM attains the required information by using techniques such as overlaying and buffering with the help of structured query language.

However, the model uses a list of points that are generalised and require a lot of data and proper analysis by using GIS software. This approach requires development of several models to apply all the points on real time data. But the proposed SSM emphasises on the use of GIS and RS that applies specific factors and constraints to identify suitable sites within a short period of time.

1.1.2 A model for estimation and allocation of solid waste to bin through GIS

This study was based on the model for estimation and allocation of solid waste to bin through GIS. Vijay et al. (2005), presents a GIS-based waste management model that estimates waste generation, location of bins and frequency of waste removal from the bins. This is computed with the help of GIS using the collected data from different sources. The rate of waste generation is calculated based on the local population density and income groups. These two factors are used in GIS with other data like road elevation survey data to generate a triangulated irregular network (TIN). The TIN helps in proper allocation of waste bins throughout the study area. Different parameters are considered in the allocation like the distance between the bins and its proximity from the households. The slope of the road factor is also considered for the convenience of the handcart pullers. The national guidelines specified in 'Manual on Municipal Solid Waste Management' by Central Public Health and Environmental Engineering Organization (CPHEEO, 2000) were followed.

Although many studies exist in the area of managing solid wastes and many models have been developed (Nakakawa, 2006; Mukti et al., 2005; Guruswamy, 2000), they are suited for developed countries that already have good road networks in place. Those models cannot be applied in developing countries such as Uganda with incomplete and poor road networks.

1.2 Solid waste disposal management techniques

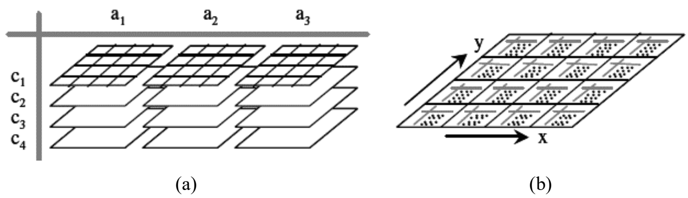
1.2.1 Spatial multiple criteria evaluation

A conventional technique is non-spatial and it uses an average or total impact that is suitable for a specific area (Tkach and Simonovic, 1997). The assumption that the area under study is not homogenous since in many cases the criteria of evaluation varies across the space. The variance in spatial multi criteria decision analysis (MCDA) and that of conventional is the presence of the spatial element. Spatial MCDA needs data on the geographic locations of alternatives or criterion values. To obtain information for the decision making process the data are processed using MCDA as well as GIS techniques.

Spatial MCDA is a process that transforms geographical data into a decision. This process consists of procedures that utilise: geographical data; the preferences of decision maker and the manipulation of the data in line with the specified decision rules. The multi-dimensional geographic data can be aggregated into one-dimensional value for the options. The variance with conventional MCDA is the large number of factors and their interrelationships. These factors make spatial MCDA much more complex and difficult (Malczewski, 1999).

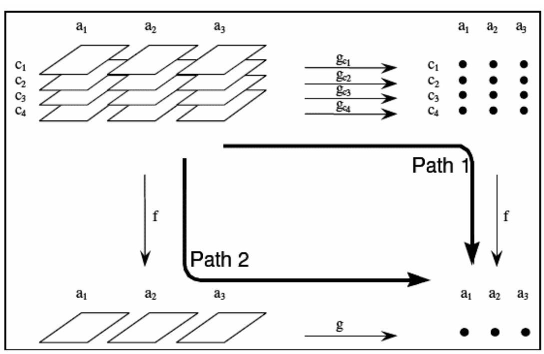
GIS and MCDM are the tools that support spatial decision makers in attaining effectiveness and efficiency. A combination of multi-criteria evaluation and spatial analysis is referred to as spatial multiple criteria evaluation (SMCE). SMCE is a vital way to produce policy-based information about spatial decision problems. According to Sharifi and Herwijnen (2003), an SMCE problem can be visualised as an evaluation table of maps as shown in Figure 1.

Figure 1 Two interpretations of a 2-dimensional decision problem, (a) table of maps (b) map of tables



If the objective of the evaluation is a ranking of the alternatives, the evaluation table of maps has to be transformed into one final ranking of alternatives. The function has to aggregate not only the effects but also the spatial component. Since the function is complicated, it is simplified by dividing it into two aggregation of the spatial component and that of criteria. These two operations can be carried out in different orders, which are visualised in Figure 2 as path 1 and path 2.

Figure 2 Two paths of spatial multi-criteria evaluation



In path 1, the effect of one alternative for one criterion is a map and this can be used when evaluating the spatial evaluation problem. In path 2, every location has its own 0-dimensional problem and can best be used when evaluating the spatial problem.

1.2.2 SMCE and Integrated planning and decision support systems

The described models have been integrated into an information system called integrated planning and decision support system (IPDSS). Sharifi and Rodriguez (2002) note IPDSS as a model that has the ability to analyse resources at all levels of management. This is the most important component of the system, which forms the foundation of model-based planning support. The IPDSS consists of three classes of models that make use of the existing data or knowledge to identify a problem, formulate, evaluate and select a proper solution. They consist of models for: processing, planning and evaluation.

The process model describes the functional and structural relationships of the elements to analyse and assess the actual state of the system. It also helps to analyse land or resources in terms of their attributes to understand how they are allotted and used (Sharifi and van Keulen, 1994; Sharifi, 2000; Sharifi and Rodriguez, 2002).

A planning model integrates the potential and capacity of resources to simulate the behaviour of a system. The model helps to understand the behaviour of the system and allows generation of alternative solutions to address a problem.

An evaluation model allows for valuation of impacts of solutions and supports selection of the most suitable way out to all users, and improves the operation of a system.

1.2.3 Analytical hierarchy processing

The analytical hierarchy processing (AHP) developed by Saaty (1980) is a technique for analysing and supporting decisions in which multiple and competing objectives are involved and multiple alternatives are available. The method is based on three principles: decomposition, comparative judgement and synthesis of priorities. In the AHP, the first step is that a complex decision problem is decomposed into simpler decision problems to form a decision hierarchy (Erkut and Moran, 1991). When developing a hierarchy, the top level is the ultimate goal of the decision. The hierarchy decreases from the general to more specific until a level of attributes are reached. Each level must be linked to the next higher level.

Typically a hierarchical structure includes four levels: goal, objectives, attributes and alternatives. The alternatives are represented in GIS database. Each layer consists of the attribute values assigned to the alternatives (cell or polygon) which are related to the higher level elements (attributes). Once decomposition is completed, cardinal rankings for objectives and alternatives are required. This is done by using pairwise comparisons which reduces the complexity of decision making since two components are considered at a time. It involves three steps:

1. development of a comparison matrix at each level of hierarchy
2. computation of weights for each element of the hierarchy
3. estimation of consistency ratio.

The final step is to combine the relative weights of the levels obtained in the above step to produce composite weights. This is done by means of a sequence of multiplications of the matrices of relative weights at each level of the hierarchy. First, the comparison matrix is squared and the row sums are calculated and normalised for each row in the comparison matrix. This process is continued when the difference between the normalised weights of the iterations become smaller than a prescribed value (Saaty, 1980).

The AHP has widespread use due to its flexibility and ease of use. It is also incorporated into GIS environment (Banai, 1993; Eastman, 1993; Jankowski, 1995) and can be used in two distinctive ways within GIS to derive weights and combine them with attribute map layers and to aggregate the priority for all levels of the hierarchy structures. In addition, the AHP can even be implemented in spreadsheet environment.

However, ambiguity in relative importance, inconsistent judgements by decision maker and the use of 1 to 9 scale can be thought of as the disadvantages of this method. The ratio scale makes sense when dealing with something like distance, or area which is natural ratio scales, but not when dealing with like comfort, image, or quality of life, for which no clear reference levels exists. Furthermore, for large problems too many pairwise comparisons must be performed (Malczewski, 1999).

2 Materials and methods

This is a logical and systematic phase that guides such kind of the study (Mujibor et al., 2008).

The study employed a descriptive design science research (DSR) approach as adopted from (Peffers et al., 2007). In addition to supporting both qualitative and quantitative data, DSR approach provides a basis for further research and use of advanced technologies to solve community problems (Carlsson, 2006; Hevner, 2007; Venable, 2011; Sein et al., 2011). DSR further allows for evolution of an artefact or model and hence creating a bigger impact that makes sense to the world (Nunamaker and Briggs, 2011).

A purposive sampling approach was used to select respondents in the phase of data collection in Gulu Municipality. A sample of 370 respondents were drawn out of a total population of 152,276 from all the divisions of the Municipality using the Morgan table for determining sample size (Krejcie and Morgan, 1970), and given questionnaires to get their opinions about the disposal of wastes.

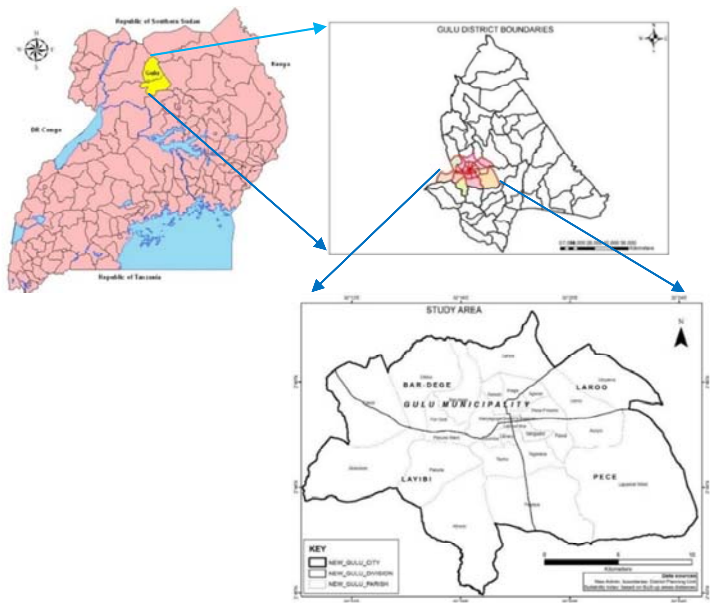
The study covered four divisions of Gulu Municipality that consist of: Pece, Layibi, Bar Dege and Laroo as shown in Figure 3 and it was done over a period of one year from June 2017 to June 2018.

A study area of 4 km^2 was considered to estimate the quantity of waste generated in the waste bins and the allocation of related services with the help of GIS. The data was collected from mainly one department, the municipal environment officer (MEO). The data collected from MEO was the boundary area of solid waste collection and the demographic data.

There were some considerations made while working on the design of the model: As the waste was of mixed category, there was no consideration of separate bins for organic and non-organic waste.

The segregation of waste is considered as an important issue and waste management without recycling is denied. The informal recycling is often viewed as negative, backward, unhygienic and incompatible with the modern way of managing wastes. On the other hand, one of the aims of modern waste management is to move ‘up the waste hierarchy’, i.e., reduce the reliance on disposal and increase recycling: “it would seem ironic to move forward by deliberately eliminating what can be a rather efficient, existing recycling system” (Wilson et al., 2006).

Figure 3 Study area (see online version for colours)



3 Findings and discussions

Gulu is an average Ugandan city situated in the heart of Northern part of Uganda (Figure 3). It is the commercial and administrative Centre of Gulu District. The city is located at 2°46’48 N 32°18’00 E, on the meter gauge railway from Tororo to Pakwach. Gulu is located approximately 200 miles (320 km), by road, north of Kampala, Uganda’s capital and largest city. The position of the Gulu Municipality and proposed new city boundaries in Gulu is illustrated in Figure 1.

The national census by the Uganda Bureau of Statistics (UBOS, 2014) estimated the population of the city at 152,276. In 2002, it was estimated at 119,430 and 38,297 in 1991.

According to the MEO, the city’s daily waste generation was estimated at over and about 10 metric tons.

The study of the existing situation made the picture clearer for the problem analysis and design considerations for future proposals. The planning which was to be carried out for the purpose of suggesting some revision to the system was possible by analysing the present waste management situation in the study area and evaluating the problems that arise due to short comings of the waste management system. “Good municipal solid waste management practices require collection of critical information which is not just for keeping the records up to date but used effectively for taking corrective measures as well as proper planning for the future” (Ramachandra and Saira, 2003).

The information of the existing situation was available from different sources. The information gathered was, the Gulu municipal city maps, interview with the employee working with waste management, and survey conducted through the questionnaire to the case study area residents. All the information from different sources were used to prepare the database.

3.1 Waste bin location data

This information about major collection points in the municipality was obtained from the municipal office. The locations of the waste bins were demarcated on the case study area map. These locations also included major markets, schools, institutions, hospitals and densely populated areas within the municipality.

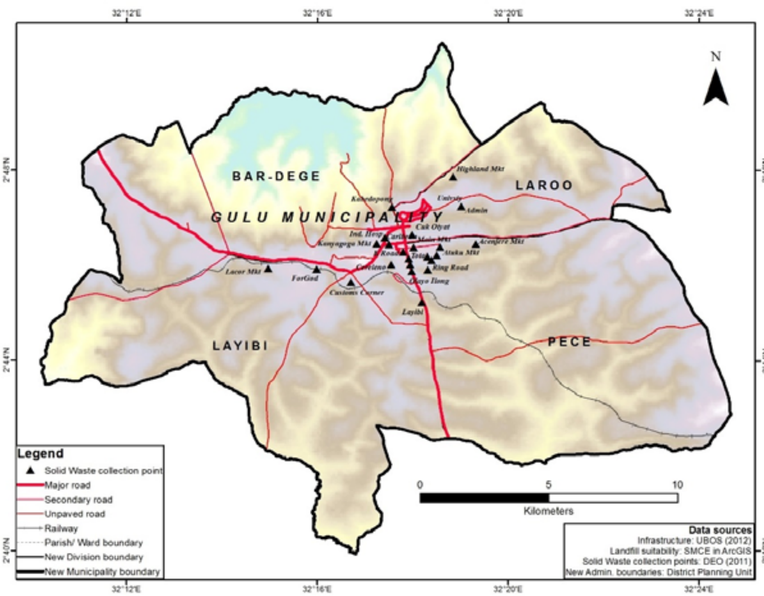
Waypoints for the proposed collection points were taken using a GPS device and the XY coordinate data obtained were used to plot the points on to a map with the respective place names added as shown in Table 1.

Table 1 Collection points attribute data in ArcGIS

Solid waste collection point				
FID	*Shape*	*X*	*Y*	*Point*
0	Point	42,463	30,665	Acenjere Mkt
1	Point	42,323	30,652	Atuku Mkt
2	Point	42,125	30,663	Caribean
3	Point	42,213	30,558	Cereleno
4	Point	42,215	30,701	Cuk Otyat
5	Point	41,979	30,517	Customs Corner
6	Point	41,845	30,567	ForGod
7	Point	42,375	30,924	Highland Mkt
8	Point	42,110	30,689	Ind. Hosp
9	Point	42,202	30,608	K Road
10	Point	42,138	30,808	Kabedopong
11	Point	42,079	30,665	Kanyagoga Mkt
12	Point	41,656	30,571	Lacor Mkt
13	Point	42,254	30,439	Layibi
14	Point	42,221	30,651	Main Mkt
15	Point	42,134	30,585	Olayo Ilong
16	Point	42,311	30,621	Pece Stadium
17	Point	42,275	30,615	Pece Vangd
18	Point	42,180	30,635	Public Library
19	Point	42,277	30,565	Ring Road
20	Point	42,208	30,585	Total
21	Point	42,407	30,811	Gulu Univsty
22	Point	42,291	30,602	Wilobo Mkt

The waypoints shown in Table 1 were downloaded into a MapSource software then plotted to generate the map of proposed collection points as shown in Figure 4.

Figure 4 Waste collection points in the city (see online version for colours)



3.2 Gulu municipal solid waste management working pattern

This explanation is about the present situation working pattern and the work distribution amongst the different employees concerned with the solid waste management. The information about the working pattern is available from the interview with the MEO. The municipal solid waste is managed by the Gulu Municipal Council.

There is no particular system in place to manage the solid waste. There is also a municipal health inspector (MHI) who monitors the solid waste management in the Municipality and a district health inspector (DHI) for the entire district. The following were the results obtained:

- There are general guidelines for municipal waste management which are set by the government authorities, in particular, the National Environmental Management Authority (NEMA) guidelines. But also there are some modifications made as per the local requirements, resources and area restrictions.
- A group of about 20 employees are contracted or outsourced to collect rubbish around the city centre. The garbage is picked by trucks from specific points on specific days of the week. Citizens empty waste bins into the trucks that move around the residential areas. There are some municipal casual labourers who sweep

the roads on specific days. The garbage is collected and damped on to trucks which ferry them to temporary dumping sites; nothing is done to the wastes after that. There is also public dumping, i.e., some citizens dig their own rubbish pits.

- The waste collection vehicle starts at 8:30 am for its waste collection trip. The waste is collected manually by the labourers. There are three (3) trucks in total. The helpers along with the waste collecting labourers and the citizens bring the waste and throw the garbage in the truck. The major waste collection points in the municipality include major markets, densely populated residential areas, schools, and hospitals.
- In terms of the working system of waste management in the municipality, we found that there were about three trucks which collect wastes from a few collection points within the municipality and damp the wastes in an open damping site in one of the divisions of the municipality on a daily basis.
- Generally there were three methods which were in practice for waste collection, viz: daily road sweeping, door to door garbage collection and public dumping, i.e., citizens throw waste in the bins on their own.
- On how the system deals with the waste collected from different sources, we found out that road sweeping is done daily and collected waste is combusted or dumped into bins. Sweeping and combusting is done by municipal appointed employees. Door to door collected garbage is put into the nearest waste bin. Collection and putting the waste into bins is done by municipal appointed employees. Public dumping is done by the citizens themselves by throwing waste in the bins in their nearby proximity on their own.
- On the method of carrying wastes to the bins from the different sources, the official said that the swept wastes and the door to door collected wastes are carried in hand carts to the waste bins.
- The vehicles used in the whole system are some three (3) trucks which collect the wastes from the bins to the temporary damping sites. On an average 10 to 20 metric tons per day (i.e., 10,000 to 20,000 kg/day) and there is no specific lifting pattern, but as they are acquainted with the areas allotted to them so they do it on the basis of their experiences and as per the situation that arises.
- On the categories of wastes collected in the municipality, we found that there are almost all types of waste like domestic, vegetable, food, paper, fabric, metal, rubber, and plastic waste.
- At present the whole waste of the municipality is collected and dumped into an open ground at Pageya and Bungatira in the outskirts of the municipality. The open ground is about 2 acres in area. It is in the outskirts of the municipality, but is in the close proximity of the town. But the residents of the area are now complaining about the inconvenience caused to them due to the accumulated waste at the ground.
- The problem with the open ground damping is that the areas in the proximity of ground are getting contaminated. Air pollution is caused which results in bad odour. People complain about health problems like malaria and fever, there is a frequent illness amongst nearby residents. Also there has been increase in the rate of mosquitoes, flies and other insects. The reason behind the inconvenience is due to

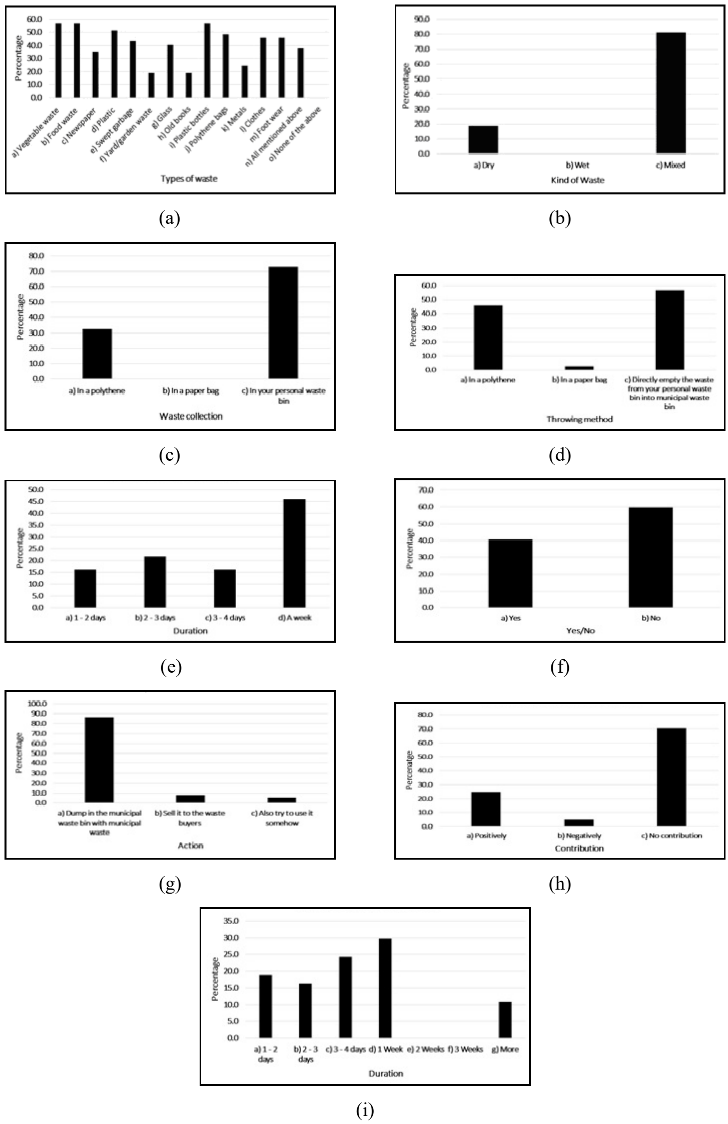
the improper maintenance of the dumping ground. Waste is not segregated and even there is no technical approach to it. Less care is taken of the dumping ground; there is no proper boundary to it. It is open to surrounding which invites animals and birds.

- There is a lack of proper managed dumping ground. There should be a technically sound landfill. All the waste is simply dumped without segregation. There is no other technique used for waste disposal, but there are some people who collect the metallic scraps from amongst the waste for sale: The scraps are transported to factories in Kampala that manufacture metallic products.
- Three trucks have been allotted, which always break down and take long to be repaired. The number of employees and vehicles are insufficient, more employees need to be recruited and more trucks need to be provided by the government as Gulu will become a city in future.
- However, the study also found out that there is a complaint registration system in place. The environment officer has a complaint register in the office to receive complaints. They note down the complaints made by the public and try to attend to the complaints on that day or on the next day.
- The waste disposal technique used is open burning, dumping on open grounds. The open damping grounds are located in Pageya and Bungatira in the outskirts of the municipality. There are no landfills in place but open damping is practiced in areas that are open (open grounds). There are no other modern techniques in place but future plans are there to start recycling the wastes that are recyclable.
- New initiatives to be implemented included, amongst others: Use of skips to be re-introduced; 25 points to be identified; 23 were identified by researcher; 2 skip loaders to be acquired; segregation of wastes (organic and other wastes) and a compost plant to be set up at Pabwo in Oitino Parish, Bar Dege division.
- After this, about 60% of the municipal waste will be collected. Benefits will include income from manure, and creation of jobs for the locals to work in the plant.
- All in all, the technique in use for solid waste management is old, the employees are inadequate, the equipments used are inappropriate and insufficient and the trucks are high which leads to loading difficulties.

3.3 Questionnaire analysis and discussion for local residents

Using purposive sampling and Morgan table (Krejcie and Morgan, 1970) at 95% confidence level and 5% margin of error, a group of 370 respondents were drawn from the divisions of the municipality and the questionnaire distributed to them. The results are calculated in percentages from the total number of persons who answered the questionnaire. A summary statistical analysis was done in MS Excel for the preference to each option by citizens and was calculated in percentages. Figure 5 shows the results obtained from the analysis of the data collected.

Figure 5 (a) Waste thrown in municipal waste bin (b) Percentage of kinds of waste (c) Storage/collection of wastes (d) Throwing of wastes (e) Duration of waste storage (f) Feasible to sort wastes (g) Recyclable waste (h) Contribution of waste buyer (i) Storage of recyclable waste



The most content of waste thrown into the municipal waste bins are vegetable waste, food waste, and plastic bottles; each with 56.8% of the respondents [Figure 5(a)].

In terms of kinds of wastes generated [Figure 5(b)], all the wastes generated by the households are of both dry and wet or semi wet nature and the swept garbage comprises of soil, dirt and dust which is of dry type. The study found that the greatest percentage of wastes, i.e., 81.1% is of the mixed nature.

Regarding the waste storage [Figure 5(c)], it is seen that over 70% of residents use their personal house waste bins to collect and store the house waste.

The study also shows that most households, i.e., 56.8% throw their waste into the municipal waste bin by directly emptying the garbage from their personal bins into the municipal waste bins [Figure 5(d)]. Whereas 45.9% of the respondents also use polythene bags to collect and store the waste and throw it along with the garbage.

In terms of duration of wastes storage [Figure 5(e)], it is seen that 16.2% of residents keep the garbage for 1 or 2 days at their places and 21.6% keep for 2 to 3 days and 16.2% keep it for 3 to 4 days and the greatest 45.9% keep it for 1 week. It is clear that mostly people do not prefer to keep the waste for long. A strong reason for this is that the domestic waste being damp in nature gets spoiled very fast thus starts producing foul smell and invites flies and insects.

On the feasibility of sorting recyclable/resalable wastes [Figure 5(f)], the greatest percentage of the respondents, i.e., 59.5% said that it is not feasible to sort resalable wastes and keep them separately.

The study revealed that most inhabitants, i.e., 86.5% dump the resalable/recyclable wastes in the municipal bin with the municipal wastes [Figure 5(g)]. The rug pickers then sort the resalable wastes from the municipal waste bins.

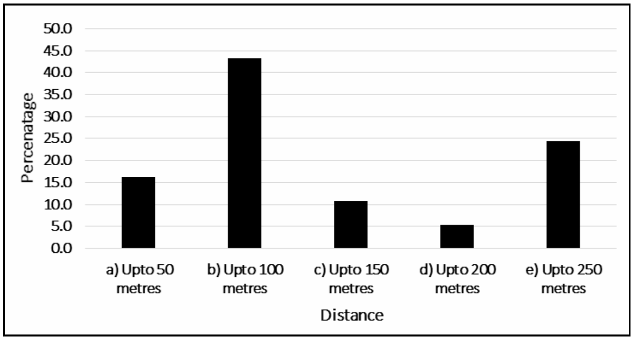
Concerning contribution of waste buyers [Figure 5(h)], 70.3% of the responds confirmed that the waste buyers have no contribution whatsoever to their personal waste management as illustrated by the graph below. This is because they do not sell the wastes directly to these waste buyers, rather, it is the rug pickers who sort the resalable wastes from the waste bins and sell them to the waste buyers. So the households do not benefit directly from the waste buyers.

The respondents also confirmed that they store the recyclable wastes for mostly a period of one (1) week just like other wastes [Figure 5(i)]. 29.7% of the respondents confirmed this, as shown in the graph.

According to CPHEEO (2000) the maximum distance between a household to a waste bin should be 250 metres. This limit is set to take care of the public convenience. So keeping this in mind the option in the questionnaire were given from a range of 50 metres and up to 250 metres with a regular difference of 50 metres. These choices were given with the intention to get the exact preferences of the citizens and it worked. The preference of majority of people was achieved.

43.2% gave a preference to 100 metres as a convenient distance for them from their places to the municipal waste bins. Whereas 24.3% wants it to be within 250 metres and 16.2% feel that it can be up to 50 metres only, 10.8% want it to be 150 metres and only 5.4% want it to be up to 200 metres. Majority of citizens prefer to be nearer so it is advisable to provide a bin within a reach of 100 metres for all the citizens. It might be less than this for many houses but it is more important that it should not be more than 100 metres for all the residents. Those who are having a bin more than 100 metres away should be considered for providing this facility within a convenient distance as shown in Figure 6.

Figure 6 Convenient distance to wastes bins



3.4 Problem at hand

Up till today all the garbage from the municipality of 150,000 inhabitants is dumped in and around wetlands, swamps and temporal landfills. However, due to an increase in environmental awareness, the municipality of Gulu has decided to construct a proper waste disposal site.

For this purpose, assistance from the district environmental officer (DEO) and MEO was sought. After a thorough consultation with the MEO and the DEO, field studies were conducted and the following criteria in selecting areas suitable for waste disposal were considered.

3.4.1 Geographical criteria

3.4.1.1 Constraints 1

- The waste disposal site cannot be built on landslides which are active or may become active in the future.
- The waste disposal site can only be constructed in areas which do not have an important economic or ecological value.
- Areas should have sufficient size/capacity (at least 20 hectares) to be used as a waste disposal site for a prolonged time.

3.4.1.2 Factors 2

- The waste disposal site should preferably be constructed on areas which are clay rich to avoid landslides.
- The waste disposal site should be constructed on clay-rich soils (preferably more than 50% clay).

- The waste disposal site should have a high soil thickness. The waste disposal site's soil should have a very low permeability (preferably 0.05 metres per day or less).
- The waste disposal site should preferably be located on a terrain with a slope less than 20 degrees.
- The waste disposal site should be located in areas where there is either grassland or bushes.
- The waste disposal site should preferably be located at least 200 metres from any open water or river.

3.4.2 Socio-economic criteria (factors)

- The waste disposal site should preferably be constructed on areas with the least important economic or ecological value.
- The waste disposal site should preferably be located within 2 km away from the built up areas of Gulu City.
- The overall site location should be at least 100 metres from roads and railways for accessibility purposes.
- The landfill should be at least 2 km away from gazetted areas.
- The price of the final site should be as low as possible to enable easy acquisition by the municipal authority.
- Once a waste disposal site is introduced, the land value of the surroundings and other locations will change. The effect on the land-value should, if possible, not be very negative for land that currently has a significantly high value.
- Once a waste disposal site is introduced, the pollution of the surroundings and other locations will change. The effect on the pollution should be as low as possible to locations that are sensitive to it.

3.4.3 Environmental (climatic) criteria (factors)

- The waste disposal site should be constructed in areas with low annual rainfall.

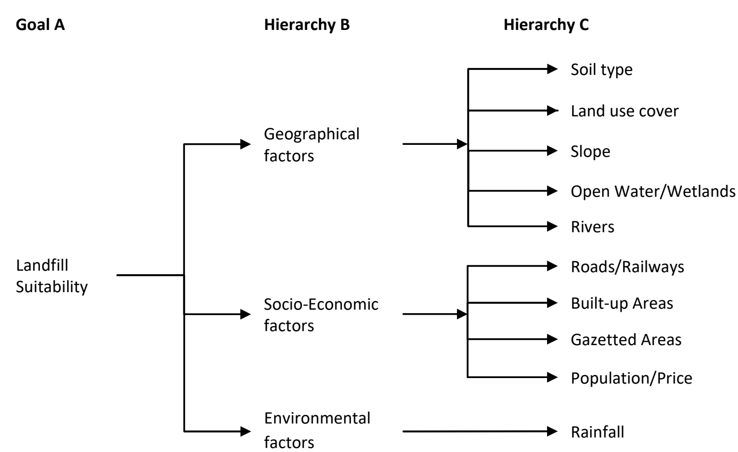
3.4.4 Summary of map layers for sites selection

Table 2 shows a summary of the factors that were used in the identification of the suitable damping sites. They include the geographical, socio-economic and environmental (climatic) factors.

Table 2 Summary of map layers for site selection

S/N	*Factor/layer*	*Description*
1	Land use	A map whereby each pixel is classified in one of five classes: 'grassland', 'forests', 'bushes', 'rivers', 'surface water'.
2	Slope	A map whereby for each pixel the average slope of the corresponding area is stored, as a numerical value (in degrees).
3	Soil	A map whereby for each pixel, the soil texture of the area is stored as a numerical value (in raster form) and classified in one of two classes: 'clay rich' or 'less clay rich'.
4	Distance_from_ Open_water/Wetlands	A map where for each pixel, its distance from the nearest open water or wetland is stored as a numerical value (in metres).
5	Distance_from_Rivers	A map whereby for each pixel, its distance from the nearest river is stored as a numerical value (in metres).
6	Distance_from_ built_up	A map whereby for each pixel, its distance from the nearest built-up area is stored, as a numerical value (in kilometres).
7	Distance_from_ Roads/railways	A map whereby for each pixel, its distance from the nearest road/railway is stored as a numeric value (in metres).
8	Distance_from_ gazetted_areas	A map whereby for each pixel, its distance from the nearest gazetted area is stored (in kilometres).
9	Population/price	A map whereby each pixel is classified in one of two classes: 'high' or 'low'.
10	Rainfall	A map whereby each pixel is classified in one of two classes: 'high rainfall' or 'low rainfall'.

Figure 7 Hierarchy model of landfill suitability



Source: Adapted from Wang et al. (2009)

3.5 Site selection process

3.5.1 Calculating criteria weights by AHP

The hierarchy of landfill siting was established and Figure 15 is the decision hierarchy model of landfill siting in the case. We used ten criteria in the computation process, which were divided into three main groups. The first group includes geographical criteria that limit the analysis to particular geographic areas. The second group is socio-economic factors and the third group was based on climatic criteria only, i.e., annual rainfall. The examined criteria were selected based on the relevant international literature (Wang et al., 2009; Nakakawa, 2006) and the regulations (NEMA, 2001; EPA, 1998) in Uganda on landfill siting. All the criteria are shown in Figure 15.

Pairwise comparisons of all related attribute values were used to establish the relative importance of hierarchy elements. Decision makers evaluated the importance of pairs of grouped elements in terms of their contribution to the higher hierarchy. Finally, all the values for a given attribute were pairwise compared. The weight of each factor in each hierarchy was calculated through pairwise comparison of their structural models and the criteria weight (W) was calculated (Table 3) by normalising the weight of each factor. W is the criteria weight, i.e., the weight of every last factor, in Figure 7, to the goal hierarchy (A).

Table 3 Criteria weights of all factors for site selection

Goal A	*Hierarchy B*	*Hierarchy C*	*Weight (W)*
Landfill suitability	Geographical factors	Soil	0.05
		Land Use	0.07
		Slope	0.10
		Open water/wetlands	0.15
		Rivers	0.15
	Socio-economic factors	Roads/railway	0.10
		Built-up areas	0.08
		Gazetted areas	0.15
		Population/price	0.10
	Environmental factors	Rainfall	0.05
Total weight			1.00

3.5.2 Spatial multi-criteria evaluation application in identifying potential sites

In this study, 12 input map layers including man and animal habitats (built up areas), surface water (swamps, rivers and lakes), land use (agricultural land, forest land, grassland, bushes and special land), slope, price of land, collection points, roads/railway, gazetted areas, soil and rainfall were used. The map layers were obtained from the NFA and MUINER. The population data was obtained from the UBOS. Geographical features were first extracted by ArcGIS software. Different criteria were used to obtain GIS data sets of the buffer zone. Buffer zones were built and divided into five grades according to these criteria. Each grade was assigned a different score (1–5). The higher the score is, the more suitable the area is for landfill siting.

3.5.2.1 Soil type

According to NEMA (2001) (solid waste management law and waste landfill criterion), a sanitary landfill should be located in an area which is clay rich to avoid leachate and silting. Therefore, a two class criteria (5: clay rich – 25% and 2: less clay rich – 23%) was applied to the soil layer to come up with the soil suitability index map shown in Figure 8.

Figure 8 Soil suitability index map (see online version for colours)

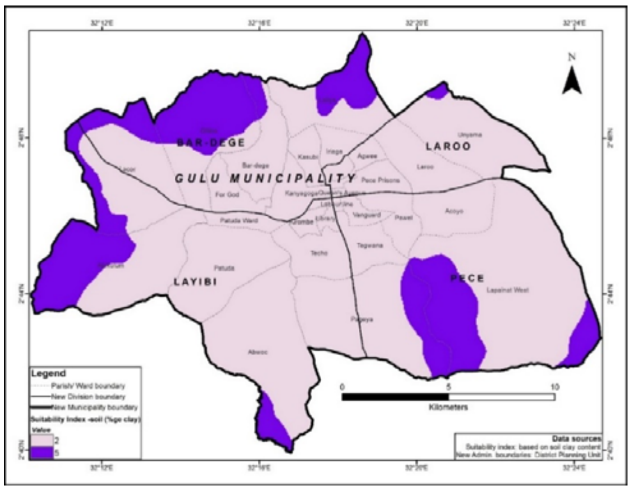
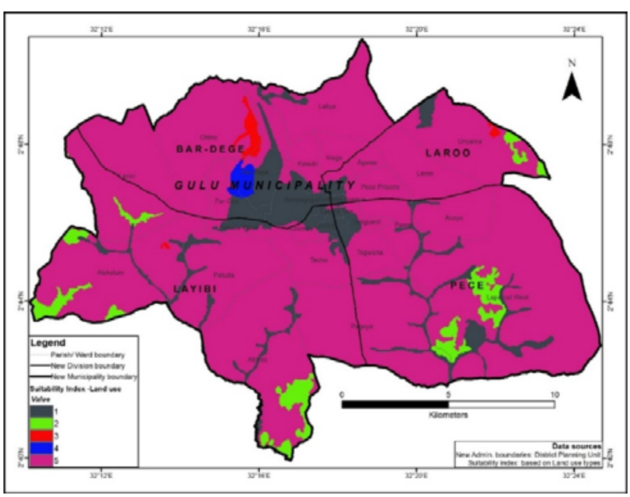


Figure 9 Land use suitability index map (see online version for colours)



3.5.2.2 Land uses

Agricultural land use prevails in the study area. A number of forest reserves are present in the study area, which were excluded from further consideration. To detect suitable areas for landfill, data from NFA and GIS database were combined. Two types of land uses were distinguished by combining these sources of information:

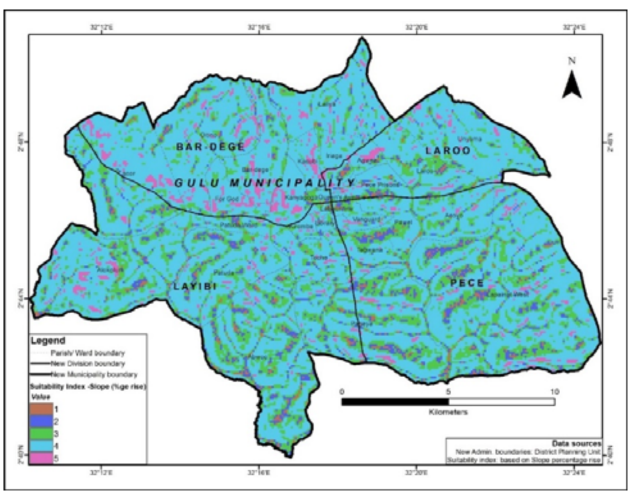
1 unsuitable for landfill, i.e., dense and sparse forests, which received a score of 1

2 uitable for further consideration, i.e., mainly agricultural and unused grassland and bushes, which received a score of 5 as shown in Figure 9.

3.5.2.3 Slope of the land surface

The slope of the land surface is a crucial factor as far as construction costs are concerned, such as very steep slopes will lead to higher excavation costs. The slope of the land surface was calculated on the pixel basis using the digital elevation model (DEM) of the study area (Figure 10), as a percentage ranging from 0 to 20%. Then the above values of the slope of the land surface were transformed to a scale of 1–5. Function membership of areas which had the value of 15–20% was 1 (lowest suitability), and that of other areas which had the value of 0–5% was 5 (highest suitability).

Figure 10 Slope suitability index map (see online version for colours)



3.5.2.4 Open water bodies

According to NEMA Uganda Solid Waste Management law, a 50 m buffer zone should be maintained around significant surface water bodies. In the study area such a zone has been created around dams, swamps and wetlands. A 50 m buffer zone was scored as 1, a 100 m buffer zone was scored as 2, 150 m scored as 3, 200 m scored as 4, and buffer zones greater than 200 m were scored as 5. The score increased by degrees as distance increased from the buffer zone as shown in Figure 11.

Figure 11 Open water/wetlands suitability index map (see online version for colours)

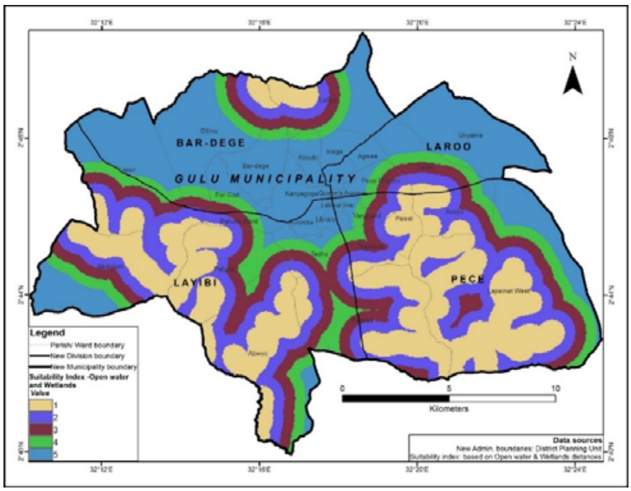
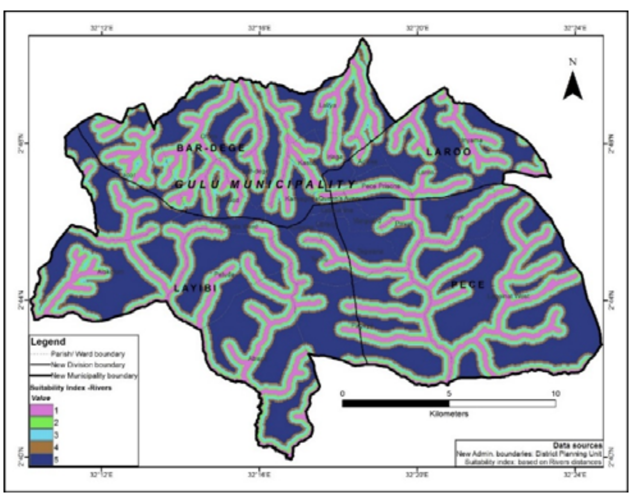


Figure 12 Rivers suitability index map (see online version for colours)



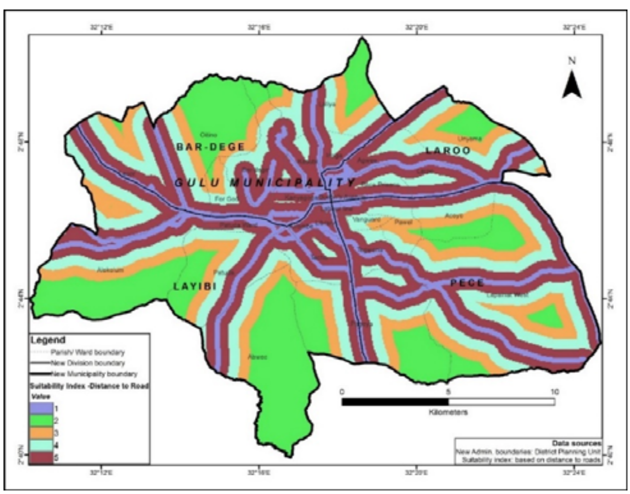
3.5.2.5 Rivers

A landfill site should not be located in areas less than 200 m in distance from a river. In the study area such a zone has been created around rivers and streams. A 50 m buffer zone was scored as 1, a 100m buffer zone was scored as 2, 150 m scored as 3, 200 m scored as 4, and buffer zones greater than 200 m were scored as 5. The score increased by degrees as distance increased from the buffer zone as shown in Figure 12.

3.5.2.6 Roads/railway

A 100 m buffer zone was set on each side of highways and railways. The closer the distance to highways and railways the lower the suitability score; the lowest value was 1. Roads other than highways and railways were treated as equal; the closer the distance the higher the score. Additional costs for road construction in areas far away from present roads make them less attractive. A very low suitability value, however, was assigned for areas within a distance of 50 m from existing roads so that landfill vehicles would not interfere with current traffic. So the closer the distance the higher the score; the highest score was 5 as shown in Figure 13.

Figure 13 Roads/railway suitability index map (see online version for colours)



3.5.2.7 Built-up areas

For safety, a 2 km buffer zone was applied around all the built-up areas in the study area. A 500 m buffer zone was scored as 1, a 1 km buffer zone was scored as 2, 1.5 km scored as 3, 2 km scored as 4, and buffer zones greater than 2 km were scored as 5 as shown in Figure 14.

Figure 14 Built-up areas suitability index map (see online version for colours)

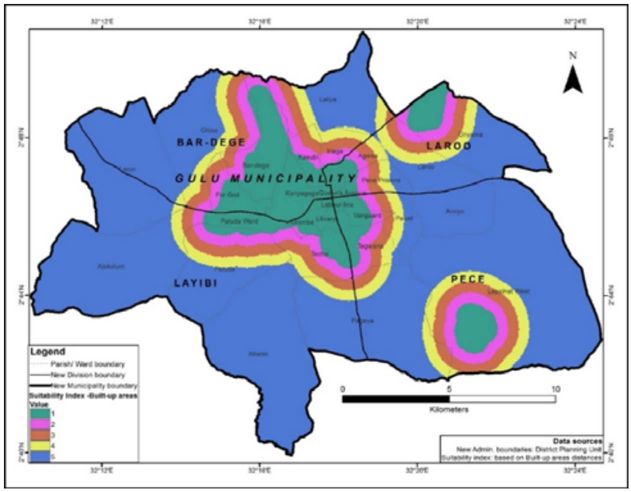
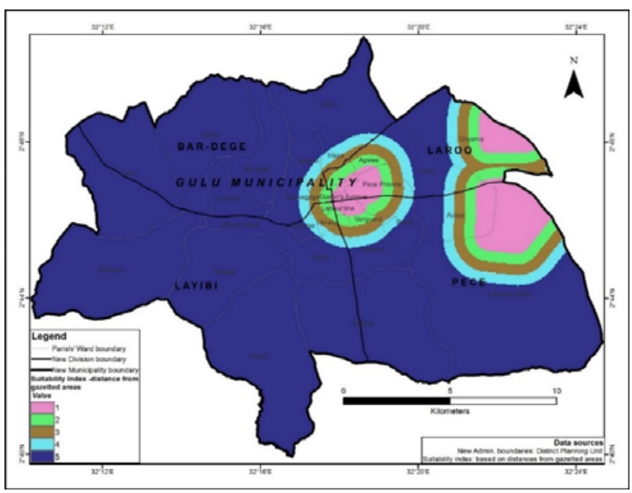


Figure 15 Gazetted areas suitability index map (see online version for colours)



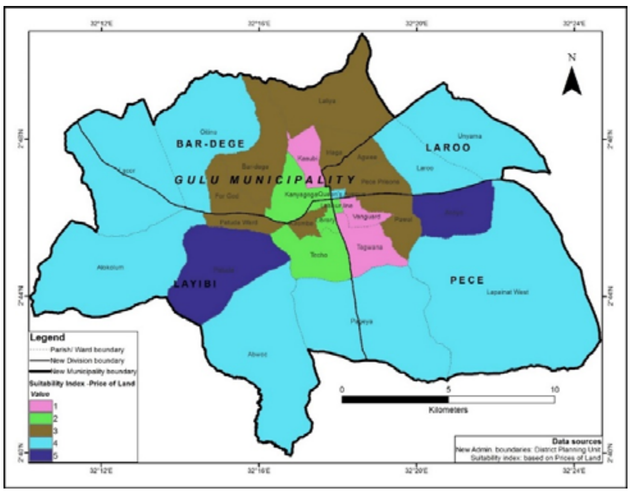
3.5.2.8 Gazetted areas

The gazetted areas were mainly forests reserves of Abera, Laroo and Opaka forests. A landfill cannot be constructed less than 2 km from a gazetted area. Therefore, A 500 m buffer zone was scored as 1, a 1 km buffer zone was scored as 2, 1.5 km scored as 3, 2 km scored as 4, and buffer zones greater than 2 km were scored as 5 as shown in Figure 15.

3.5.2.9 Population/price of land

The land price in Gulu has been on the increase in the past decade due to the prevailing peace. Coupled with the prospects of becoming a city, prices of land have sky-rocketed and land has become extremely expensive. The price of land in the study area was considered in terms of the population distribution of the parishes within the city. The highest price areas, are those areas with high numbers of settlements and built up areas which scored 1 and the least expensive; areas with low population, scored 5. So suitability scores increased as land prices decreased. The result is shown in Figure 16.

Figure 16 Price suitability index map (see online version for colours)



3.5.2.10 Rainfall pattern

For rainfall pattern in the study area, a map whereby each pixel is classified in one of two classes: 'high rainfall' or 'low rainfall' was generated. The recommended areas suitable for the damping site are those areas that receive low annual rainfall.

The results show that the western part of the city is the most suitable since it receives a relatively low annual rainfall compared to the eastern part of the city as shown in the suitability index map in Figure 17.

Figure 17 Rainfall pattern suitability index map (see online version for colours)

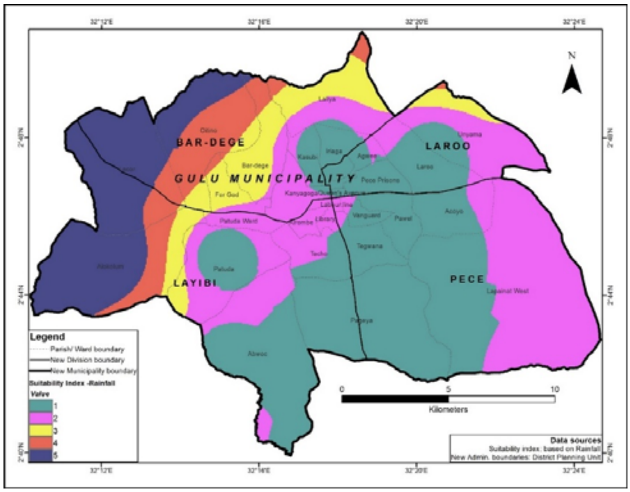
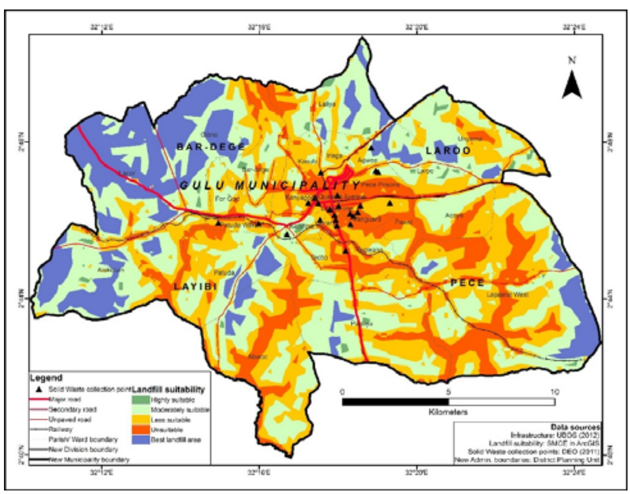


Figure 18 Aggregated suitability index map - all factors (see online version for colours)



3.5.2.11 Aggregation procedure

Factor weights are given in Table 3 after standardising all factors. The sum of all factors is 1. Corresponding maps with all factors were reclassified from grade 1 to 5 by spatial information technologies. The score was assigned based on the grade of each area. Then, the final suitability map was produced by aggregation procedure based on weight. The final suitability results were divided into five discrete categories: best suitable landfill areas, highly suitable landfill areas, moderately suitable, less suitable and unsuitable landfill areas, as shown in Figure 18. The final suitability map was generated based on the following formula implemented in ArcGIS:

$$\begin{aligned}\text{Suitability} = {} & (\text{Gazetted\_areas} * 0.15) + (\text{Rainfall} * 0.05) + (\text{Soil} * 0.05) \\ & + (\text{Road} * 0.1) + (\text{Price} * 0.1) + (\text{Slope} * 0.1) + (\text{Land\_use} * 0.07) \\ & + (\text{Rivers} * 0.15) + (\text{Wetlands} * 0.15) + (\text{Built\_up\_areas} * 0.08)\end{aligned}$$

3.5.3 Final site selection using sizing procedure

To get the best suitable landfill area for Gulu, the methodology described by Aivaliotis et al. (2004), as quoted by Wang et al. (2009), was adopted. The average daily solid waste production per capita in Uganda in 2001 was reported about 0.55 kg/capita/day and the average density in a landfill after compaction is between 100 and 160 kg/m^3 (NEMA, 2001).

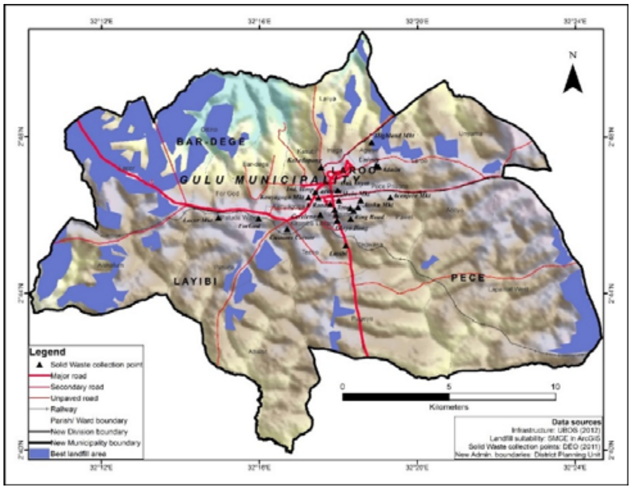
For the study area, the estimated solid waste quantity M is 31,792,183.28 tons for a 25-year operation period, assuming a 2% population increase per 10 years and a constant average waste production per capita per year. According to Aivaliotis et al. (2004), size A of the required surface area of the landfill, for waste quantity M (in tons) to be placed, will range from A = (M/1.76)0.725 to A = (M/2.55)0.725. Thus the required landfill area ranges from 139,457.10 m^2 to 182,467.52 m^2, for the two mentioned shapes. The sizing analysis process for the best suitable landfill is shown in Table 4.

Table 4 Sizing analysis for best suitable landfill

Provisional municipality population 2014	152,276
Estimated Amount of waste in kg/day (population × daily waste production per capita)	83,751.8
Amount per year (amount per day × 365)	30,569,407.0
4% increment of Pop in 25 years (population × 4%)	6,091.0
Total Pop_25 years (population + increment)	158,367.0
Waste generated_25 years/day (tot pop × waste per capita)	87,101.87
Waste/year (waste generated × 365)	31,792,183.28
Average tonnage in kg per cubic metre (bulk density of solid waste)	160
Cubic metres needed (annual waste/kg per cubic metre) (waste/density)	198,701.15
Capacity of landfill in hectares (cubic metre/10,000)	19.87

The higher value, i.e., approximately 20ha, has been used during siting calculation conservatively. According to landfill size requirements, the best possible landfill sites (>=20 ha) are shown in Figure 19; the good possible landfill sites are shown (<20 ha) in Figure 18.

Figure 19 Best landfill areas suitability index map (see online version for colours)



The areas in different classes in each parish and their area ratios to the total study area are presented in Table 5. The best suitable and recommended landfill areas account for 42.03% and the highly suitable landfill areas 57.97%. Furthermore, most of the candidate areas are in the suburban parishes of Laliya, Lacor, Oitino, Lapainat West and Alokolum. For example, there are twenty nine (29) best candidate landfill sites for those which can be used for 25 years: Four (4) in Laliya, four (4) in Lacor, three (3) in Oitino, three (3) in Alokolum and three (3) in Lapainat West parish. For a landfill which can be used for at least 20 years, good landfill candidate sites are mainly in Techo, Bardege, Laro, Pageya, Unyama, Alokolum, Lapainat West, Oitino and Laliya parishes.

Table 5 Number of classes of landfill sites and the percentages of the total study area

S/N	*Parish name*	*Highly suitable landfill areas*	*Best suitable landfill areas*	*Percentages of best landfills*
		Area (A) < 20 ha	*Area (A) >= 20 ha*	
1	Abwoc	1	2	6.90
2	Acoyo	0	0	0.00
3	Agwee Ward	0	1	3.45
4	Alokolum	4	3	10.34
5	Bar-dege Ward	3	1	3.45
6	For god Ward	1	0	0.00
7	Iriaga Ward	2	1	3.45
8	Kanyagoga Ward	0	0	0.00
9	Kasubi Ward	1	0	0.00
10	Kirombe Ward	1	0	0.00

Table 5 Number of classes of landfill sites and the percentages of the total study area (continued)

S/N	*Parish name*	*Highly suitable landfill areas*	*Best suitable landfill areas*	*Percentages of best landfills*
		Area (A) < 20 ha	*Area (A) >= 20 ha*	
11	Labour line Ward	0	0	0.00
12	Lacor	1	4	13.79
13	Laliya	4	4	13.79
14	Lapainat West	3	3	10.34
15	Laro	4	1	3.45
16	Library Ward	0	0	0.00
17	Oitino	3	3	10.34
18	Pageya	5	2	6.90
19	Patuda	0	2	6.90
20	Patuda Ward	0	0	0.00
21	Pawel	0	0	0.00
22	Pece Prisons Ward	0	0	0.00
23	Queen's Avenue Ward	0	0	0.00
24	Techo Ward	3	0	0.00
25	Tegwana Ward	0	0	0.00
26	Unyama	4	2	6.90
27	Vanguard Ward	0	0	0.00
Total		*40*	*29*	*100.00*

3.6 Conclusions

The spatial model proposed in this research study was designed for planning the allocation of suitable solid waste damping sites and Optimisation of urban solid waste collection through GIS use in the case study area (Karagiannidis et al., 2006). There were several aspects taken into consideration in planning the waste management by evaluating the waste bins allocation. First was to analyse the location of the existing waste bins in the area. The planning concern was to verify the convenience and inconvenience of the users from the existing bin location. This was done by checking the location of bins for a convenient proximity distance for all the users and also for the inconvenience to the users due to close proximity of the bins to sensitive land uses. The collection points were identified and mapped based on population density, built-up areas, schools, hospitals and major markets.

The identification of suitable damping sites was carried out using the AHP (Saaty, 1980; Erkut and Moran, 1991) and SMCE (Mujibor et al., 2008) using a number of factors including socio-economic, geographical and environmental factors. Criteria Weights were assigned to the various factors using pairwise comparison in order to come up with the suitability index maps for each of the factors and later aggregated to come up with the final suitability map. A sizing procedure (Aivaliotis et al., 2004) was later used to identify areas that were more than 20 hectares in size and that were projected to be usable for the next 25 years. The best suitable damping sites were found to be in the western part of the city around the areas of Lacor and Oitino parishes.

We therefore present a case study that utilises spatial information technologies and AHP in selecting landfill candidate sites. Optimal and back-up sites were selected for waste landfill candidate sites in Gulu, Uganda. Because this study takes into account both environmental and economic criteria, the process by which the model selects landfill sites is suitable for rapidly developing cities in developing countries.

We set a different value for each criterion, a critical issue in the factor standardisation process. A classification scheme was applied for criteria. For example, when considering proximity to waste production centres, areas which are 100 m from waste production centres were more suitable and assigned higher score because of lower transportation costs.

We achieved our objective through the application of order weights. It is clear that assignment of factor weights is based on previous knowledge of the factor characteristics and the particularities of the study area, as well as on the experience of the experts involved in the weight assignment process. A weight was assigned as objective as possible by applying techniques like the AHP. In the final aggregation process, factor weights are evaluated by both factors, environmental and economic, as they both play a very important role in siting a waste landfill.

This case study illustrates the process of identifying a single or a few optimal sites. All candidate sites based on the environmental and economic factors (McKechnie et al., 1983) were aggregated based on their weights and screened by sizes. Because our method allows site suitability to be determined in relation to the maximum possible operational period of a candidate site, it is very practical for real-world planning. In the end, the best landfill areas were given, and they can be taken as the optimal landfill candidate sites. The better landfill areas can be taken as back-up landfill candidate sites.

The increasing generation of municipal solid waste in Gulu is one of the greatest challenges faced by governmental authorities. The development of our model was motivated by the desire to mitigate the impact of landfill sites on the environment, public health and economy. We have integrated GIS and a multi-criteria evaluation technique, AHP, in the assignment of site suitability for landfills. Environmental and economic factors were both considered in the computation process, including thirteen criteria categorised in three factors. Intermediate suitability maps were produced for all criteria, which were combined to create the final composite suitability map. AHP offered an objective weight assignment process. Furthermore, the use of the set of weights provided great flexibility in the aggregation procedure.

Our study provided scientific evidence for the study area. Furthermore, economic factors should be considered for solid waste landfill. The economic factors are very important factors for developing countries and districts. Landfill sites are selected not only according to environmental factors but also economic factors. These districts develop so fast that good landfill site can be considered if the best landfill areas are occupied by urban sprawl.

The siting process in this study will be very useful for waste disposal site selection in a fast-growing region. The present work offers a siting methodology and essential support to the decision maker in solving the waste management problem so that a deeper understanding can be gained in environmental decision making.

3.7 Recommendations

There are several issues that can be considered for future studies. The important issue is to first take those ones which can be practically possible to implement in the area with the consideration of the system constraints.

A future study suggestion which can be adopted as a next step to the proposed model for the study area is a mobile based platform be implemented for interaction between the municipal authorities and the local inhabitants in the municipality for reporting of filled up bins ready for collection.

The will aim at providing good SWM facilities to the citizens which could maintain a healthy and clean environment in an economic way. There can be lots of advancements in the system but it will have to be carried in stages according to the availability of resources.

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