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Utilisation of Multicriteria Decision Making with Remotely Sensed Data in a GIS Environment for Optimal Location of Waste Disposal Sites Around the Sokoto Metropolis, Sokoto State, Nigeria

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Abstract: Rapid population growth, technological development and urbanisation have brought about increase in the amount of waste being generated worldwide. Waste, domestic or industrial have caused serious pollution of the environment and have become a major problem globally. Population growth goes hand in hand with spatial growth because increase in population size results in increase in the use of urban space. Since, human induced environmental problems require detailed study. Environmental problems caused by waste therefore can be alleviated by proper locating of waste disposal sites through careful study and understanding of lithospheric and hydrospheric conditions around the geographical area we live on the earth surface. Remote sensing is an excellent source of data for mapping lithospheric and hydrospheric and other earth surface parameters. Similarly, Geographic Information System (GIS) is a tool that is being widely used now a days in suitability analysis because it has the ability to store, retrieve, recognize, correlate and analyse spatial relationships between these parameters. On the other hand, Multi Criteria Decision Making (MCDM) is a decision support tool highly used in GIS for suitability or optimum location analysis to arrive at the best decision by weighing importance. Currently, Sokoto metropolis which serves as the capital of Sokoto State and located in the North-Western part of Nigeria, over the years has been growing in terms of population size and related spatial growth. This has hitherto resulted in an increase in waste generation. This study therefore, utilises Multicriteria Decision Making (MCDM) with remotely sensed data in a GIS environment for optimal location of waste disposal sites around the Sokoto Metropolis. Quickbird image tiles/scenes covering the study area were acquired from the Nigerian Air Space Research and Development Agency (NASRDA) and imported into the Idris Andes Software in TIFF format where the smaller images covering the study area were mosaicked and combined with a windowed DEM image and analysed in a GIS environment using MCDM. Results has shown that the study is cost effective and indicated alternative waste disposal sites to the existing three sites around the Sokoto metropolis with more prospective alternative areas which are free from health risks and less environmentally endangering.

Key words: Environment, waste disposal sites, MCDM' Remote Sensing, GIS, Digital Elevation Model

INTRODUCTION

Population explosion has led to over exploitation of the earth's natural resources which in turn is now leading to irreparable damage to the environment. This over exploitation coupled with man's interaction with the ecosystem has depleted the earth's natural resources and triggered the natural morphodynamic processes of the earth. These two phenomena are causing natural disasters and environmental problems such as flooding, landslides, drought, desertification, etc. On the other hand rapid population growth, technological development and urbanization have brought about increase in waste generation worldwide (Khan and Faisal, 2007). Waste, domestic or industrial have caused serious pollution of the environment and is becoming a major problem globally. Population growth goes hand in hand with spatial growth because increase in population size results in increase in the use of urban space. The urban space comprises of various land uses such as residential, commercial, industrial, public etc and the activities on these land uses have bye products of different sorts including agricultural, chemical, hospital, domestic and industrial wastes. Furthermore, as a city grows spatially there is bound to be conflict in the use of land, land use succession and invasion. For example, as residential areas

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are overtaken by commercial activities, wastes of different kinds are most likely to be surrounded by residential developments.

While the human induced environmental problems require detailed study, environmental problems caused by waste can be alleviated by proper siting of waste disposal sites through careful study and understanding of lithospheric and hydrospheric conditions of the earth. This may sound simple however, waste management is considered one of the most serious problems faced by governments especially in developing countries. Therefore, adequate planning is required to manage waste in order to achieve environmental sustainability.

Conventional methods of identifying landfills and dumpsites have failed short of scientific knowledge and have therefore caused short term and long term environmental effects on the neighboring populace. Remote sensing is an excellent tool for mapping lithospheric and hydrospheric and other earth surface parameters. Similarly, Geographic Information System (GIS) is a tool that is being widely used now a days in suitability analysis because it has the ability to store, retrieve, recognize, correlate and analyze spatial relationships between these parameters. It therefore aids decision makers to link sources of information, perform sophisticated analysis, visualize trends, project outcomes and strategise long term planning goals (Malczewski, 2004).

On the other hand, Multi Criteria Decision Making (MCDM) is a decision support tool highly used in GIS for suitability or optimum location analysis to arrive at the best decision by weighing importance.

Currently, Sokoto metropolis which serves as the capital of Sokoto State is located in the North-Western part of Nigeria and over the years it has been growing in terms of population size and related spatial growth. This has hitherto resulted in an increase in waste generation. The Sokoto Environmental Protection Agency (SEPA) is an agency under the Ministry of Environment in the state and it is solely responsible for management of solid waste around the metropolis. As part of its challenges, SEPA cannot adequately evacuate the waste generated in the metropolis on a daily basis. In addition, final disposal sites are becoming inadequate and this has hitherto increased the number of illegal collection points with an additional 150 illegal points dotting many areas around the metropolis.

The township has a sedimentary soil formation which allows easy percolation and movement of materials downwards to ground water. It has also been established that ground water recharges surface water. Consequently, improper location of dumpsites could result in short and long term environmental and health impacts because of leachate. According to Omar, Sokoto State has been experiencing severe environmental degradation because of drought and desertification and it can be worsened by poor management practices including waste management.

Traffic and transport routes are equally an integral part of waste management. There are three existing sanitary landfills located within Sokoto metropolis namely, Kwannawa, Gidan Dare and Gagi. However, out of these three official landfills in the metropolis two have been abandoned partly due to accessibility as well as competency of uses because areas around these sites are already giving way for residential land uses. For example, due to urban expansion, residential developments have taken over the Gidan Dare landfills (land use succession) and nearly taken over the Gagi landfills (land use invasion) rendering them unfit for waste disposal.

In the current circumstances, no leachate containment or treatment and no odor or vector control exists. This contribute to hazards and nuisances to the people living around these areas. It is not very clear whether necessary guidelines were taken into consideration before these sites were selected for this purpose initially. When strategies for solid waste disposal are formulated and adopted, agencies responsible for waste management often overlook some important factors or criteria that make disposal of solid waste a poorly performed service resulting in environmental degradation, lack of sanitation and health problems (Khan and Faisal, 2007).

The Kwannawa landfill: The Kwannawa landfill is located off Gusau road. Based on ground truthing, this site is the main functional landfill in the metropolis and is quite far from human habitation (Fig. 1a). However, the problem is that it is inaccessible to trucks especially during the rainy season. Therefore, truck drivers opt to dispose off evacuated refuse in the landfills and dispose off in farmlands (Fig. 1b).

The Gidan Dare landfill: The Gidan Dare landfill was initially surrounded and during ground thruthing it was discovered that it has been overtaken by residential uses (Fig. 2a). Therefore the Gidan Dare landfill cease to be functional. Problems faced by the developments include collapsing and sinking of buildings because of the soft soil due to improper waste filling and closure (Fig. 2b).

The Gagi landfill: This landfill is located along the eastern bye-pass in Gagi village. Even though a small percentage of waste is still dumped alongside the Gagi landfill, it is surrounded by residential developments and

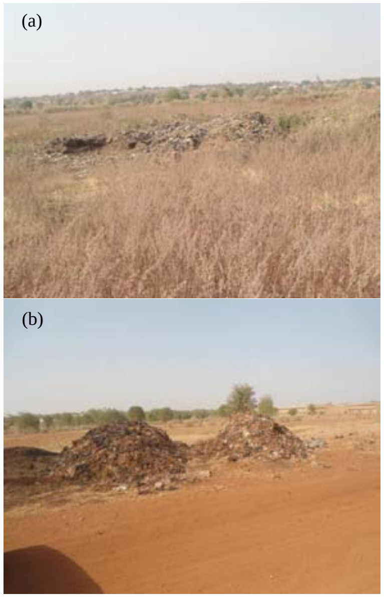

Fig. 1: a) The Kwannawa landfill; small amounts of refuse are seen in the landfill because waste is dumped elsewhere due to inaccessibility; b) road to the Kwannawa landfill. Wastes are dumped far from the Kwannawa Landfill due to inaccessibility

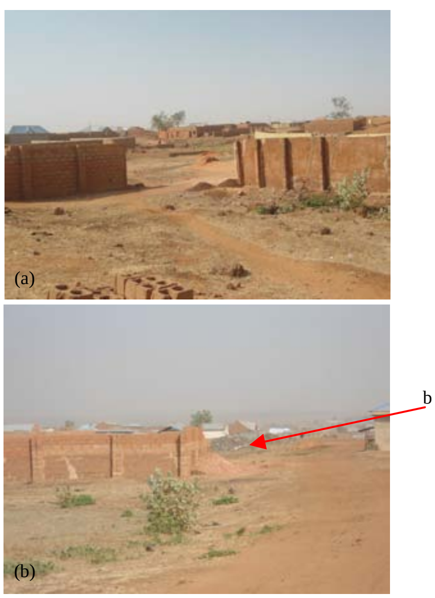

Fig. 2: a) Land use succession in the Gidan Dare Landfill; residential developments have already taken over the Landfill; b) Degrading waste can be seen between buildings shown in arrow

some developments have started invading the landfill (Fig. 3a). The continual use of the landfill could cause

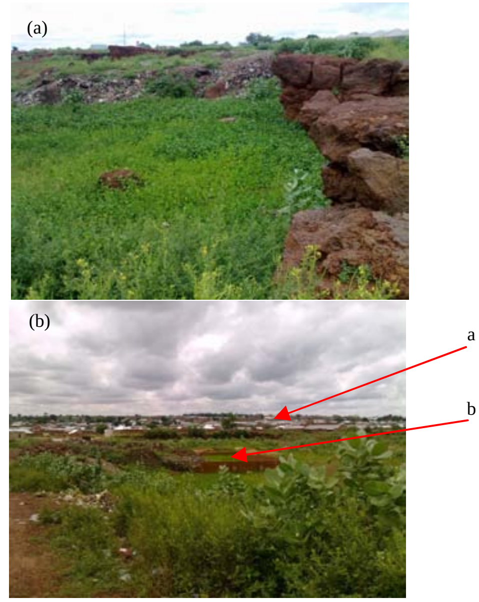

Fig. 3: The Gagi landfill; a) Inaccessible dump site; b) Despite inaccessibility there are still residential developments have taking place close the arrow at near and within the Gagi Landfill at arrow

adverse environmental and human health impacts because of its location within a residential area (Fig. 3b). This Gagi township has a sedimentary soil formation which allows easy percolation and movement of materials downwards to ground water. It is an established fact that ground water recharges surface water. Consequently, improper location of dumpsites could result in short and long term environmental and health impacts because of leachate as being experienced in this locality.

It is very clear that there is a strong contrast between the concept of sanitary land filling and what is obtainable at SEPA. Sanitary land filling is an environmentally sustainable and efficient waste management system with certain requirements or criteria. These include hydro geological isolation, formal engineering preparations, permanent control and planned waste emplacement and covering. In creating a waste disposal site, there is need to define and identify certain criteria on which suitability assessment will be based if environmental sustainability is to be achieved.

Manual methods of site selection for analysis of many factors are tedious, costly, time consuming and liable to error therefore there is a need in a paradigm shift from the conventional methods of waste disposal and site selection to a more robust, more precise and a more technologically advanced method. It is in the light of this

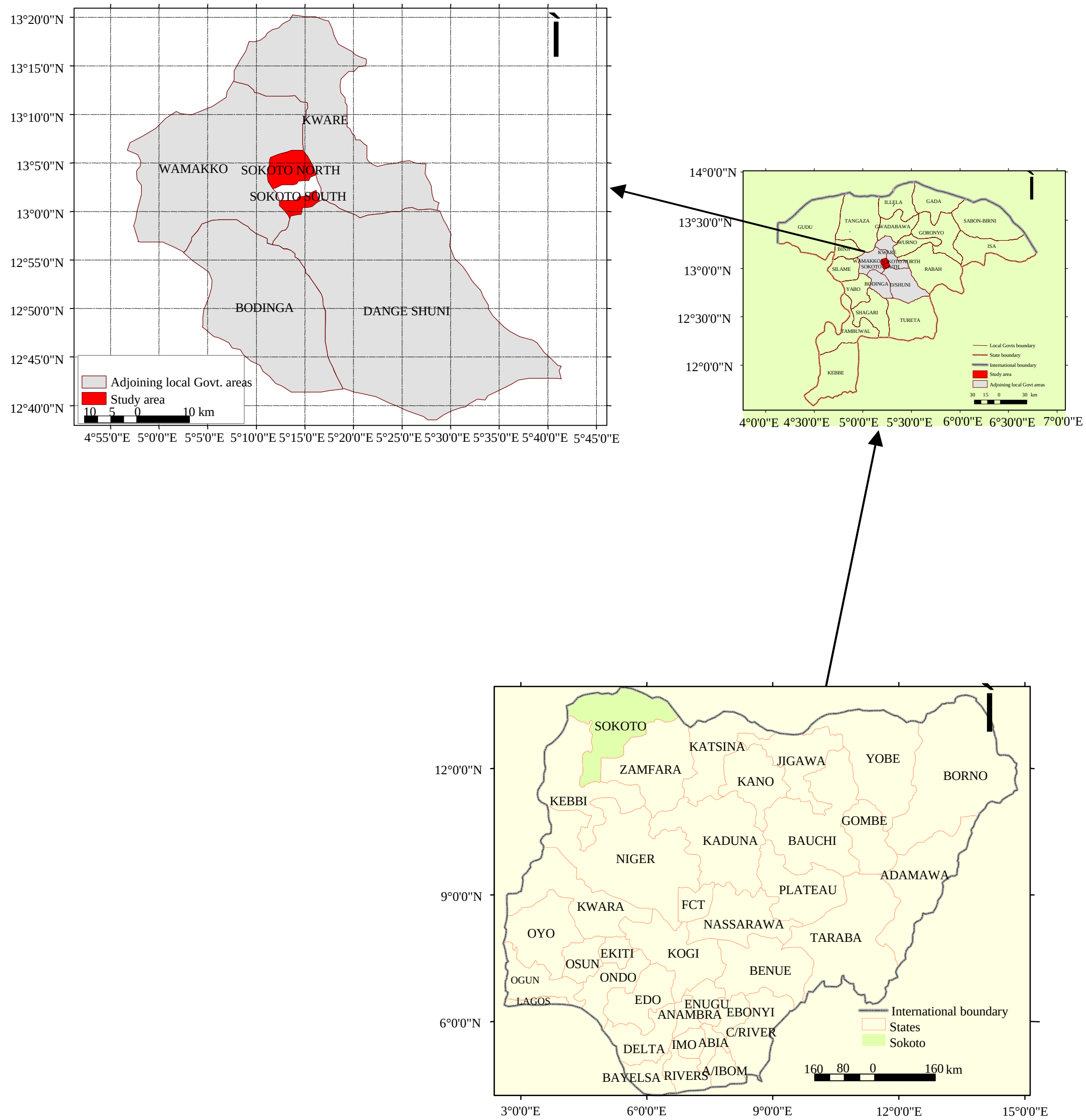

Fig. 4: Map of Sokoto State showing the location of Sokoto metropolis

that this study was undertaken for the purpose of determining suitable sites for waste disposal in Sokoto metropolis using multi criteria decision making in a GIS environment.

The study area: Sokoto metropolis is located between latitude 12°55'02"N and 13°10'05"N and between longitude 5°09'18"E and 5°17'24"E. It also lies near the confluence of Sokoto and Rima rivers (Fig. 4).

The general environment covering this study area comprises of Sokoto North, Sokoto South and part of Wamakko, Dange/Shuni and Kware Local Government Areas (LGAs). Generally, most of these areas are located within a gentle undulating plain of about 300-500 m above sea level.

Though located within the Sudan Savannah zone of the country, the vegetation comprises of sparse shrubs of <6 m high and large isolated trees hardly taller than 20 m. It has an average annual temperature of 28°C and a highest recorded temperature of 47°C in April and there are two seasons, wet and dry. The wet season begins from the month of May to September. The relative humidity is relatively low though higher in the wet season than the dry season.

MATERIALS AND METHODS

The data utilised for this study comprised of a 2003 Quick Bird Image of Sokoto with a resolution of 0.5 m; a Digital Elevation Model (DEM) obtained from the Shuttle Radar Topography Mission (SRTM) with a resolution of 90 m from USGS EROS Data Center distributes and archives; a Germin-12 Global Positioning System (GPS) receiver and a digital camera so as to identify the locations of existing waste disposal sites. Two GIS-Remote sensing doftwares namely, Idrisi Andes Version 15 and ArcGIS Vesion 9.3 for analysis (Fig. 5).

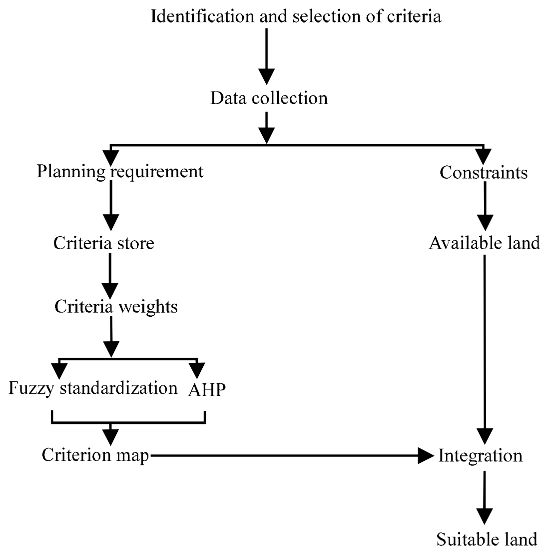

Fig. 5: Flow chart of the general methodology

Data import and preparation: To simplify the analysis, Quickbird image tiles/scenes that covering the study area were acquired from the Nigerian Air Space Research and Development Agency (NASRDA) and imported into the Idris Andes-GIS Software in TIFF format. These were later exported to ArcGIS Software where the smaller images covering the study area were mosaicked (Fig. 6a).

A Personal Geodata Base (PGDB) for the other attribute information was created in ArcCatalog so that there will be simple a data structure for storing and managing the whole geographic information in ArcGIS. This feature dataset was later created within the PGDB and projected to the projection of the Quickbird image in UTM zone 31N. Another feature dataset groups, i.e., feature classes which are stored in the same coordinate system where feature classes containing the layers were also created from the dataset showing the existing waste disposal sites such as point feature, roads as linear feature, rivers, built up and floodplain layers as polygon features. All theses were incorporated into a GIS database in real world representations with their geometric as well as attribute data.

The dataset was further transformed from analog to digital format by digitization using ArcGIS so as to allow easy storage, manipulation, analysis and visualization in a digital environment. Each feature class/layer in the feature dataset was added to the displayed mosaicked image and digitising was carried out on layer basis. Attribute data was entered on each individual layer. Finally, layers were over laid on each other to check topological relationship among features. The data created in ArcGIS were all later imported back to Idrisi Andes Software as shape files (layers) and all output files were finally stored. Finally, the location of the existing dump

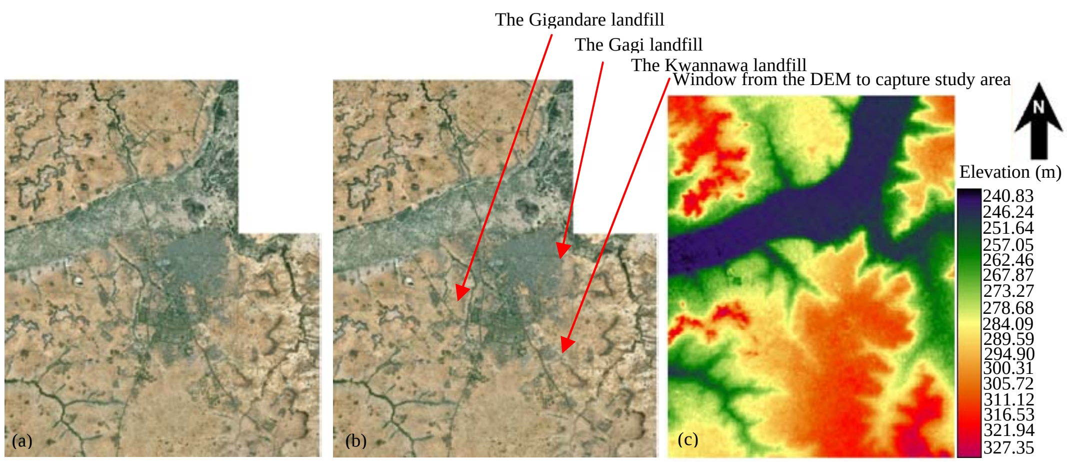

Fig. 6: a) Mosaic of the quick bird image covering the study area; b) a quick bird Image showing the existing locations of the waste disposal sites in Sokoto metropolis; c) a DEM image of the study area derived from the main SRTM Elevation Model showing all water bodies in the localities

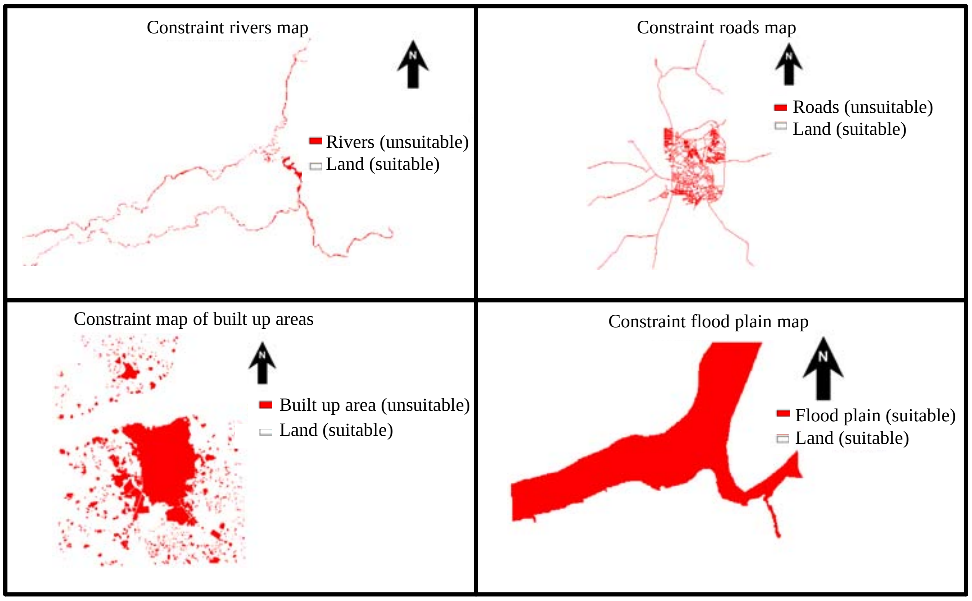

Fig. 7: Constraint analysis images showing areas of suitability and unsuitability

Table 1: Pairwise comparison matrix of factor weights

Comparison matrix	Builtfuzz	Riverfuzz	Roadsfuzz	Slopefuzz	Eigenvector of weights
Builtfuzz	1	-	-	-	0.0509
Riverfuzz	7	1	-	-	0.5998
Roadsfuzz	5	1/4	1	-	0.1545
Slopefuzz	4	1/5	2	1	0.1948

Consistency ratio = 0.09. Consistency is acceptable

sites were determined and shown (Fig. 6b). A DEM image of the of the study area was also derived from the original SRTM digital elevation model so as to complement the analysis by extracting the main water bodies round the metropolis (Fig. 6c).

All built-up areas and the flood plain in the Sokoto metropolis were also derived from the quick bird image and imported into Idrisi as a polygon feature thus:

- Flood plain: this layer covers the flood plain area along the Rivers Rima and Sokoto within the image. Features in this layer were also digitized as polygon features
- Surface water bodies: surface water bodies of Sokoto are digitized as polygon features to produce a surface water map

Rasterising the vector layers and converting them to Boolean Images: All the derived vector-based datasets to be incorporated in the analysis such as the built up areas, flood plain, roads and rivers were imported and converted to raster format as boolean images so as to differentiate open land and road, open land and built up areas, rivers, etc. while the derived DEM image of the study area was later converted to a slope image to enable further analysis.

After preparing the thematic layers that characterised the criteria for locating the waste disposal sites and creating a GIS data base for the layers, two sets of criteria were developed; the factors and the constraints. The constraints are the criteria that constrain or limit analysis to a geographic area, i.e., the areas on which waste disposal sites cannot be located. These include built up areas, flood plain, rivers and roads. Constraints were created as Boolean maps with a value of 1 and 0 where 1 indicates areas of suitability and 0 indicates areas that are unsuitable and the images are shown in Fig. 7.

For the final analysis and integration, a non Boolean standardization of factors using fuzzy analysis was carried out. Factor standardization had be done to change the disparate units of the factors into values that are comparable. In this case, the factor units were given values representing their degree of suitability. The values range on a byte scale from 0-255. Such rating was determined by consulting decision makers based on how suitability changes for each factor (Eastman, 2006). Finally, the standardised factor maps were produced for each criterion.

Factors weighing: From the standardised maps factor weights were later derived using pair wise comparison of factors, two at a time, based on their importance related to the stated objective (locating waste disposal sites). These factor weights in the form of trade-off weights show the importance of each factor relative to all the other factors indicating how they determine the factors trade offs or how they compensate each other (Table 1). When added the eigenvector of weights sums to 1 and these weights were used for the final aggregation.

Final aggregation of factors and constraints using WLC: Using Weighted Linear Programming (WLC) as adopted by Moeinaddini *et al.* (2010) each of the standardised factor maps was multiplied by its weight and were summed up. The sum was divided by the number of factors and the result multiplied by the constraints and finally a resultant suitability map showing suitable waste disposal sites in the study area was derived.

RESULTS AND DISCUSSION

Like other Multi Criteria Decision Making (MCDM) that combines and transforms input inform of spatial and attribute data into a resultant output which is the decision, results derived from this study in the form of spatial and attribute data were combined with geographical data and the decision makers' preferences thus manipulating both according to specified decision rules (Malczewski, 2004, 2006; Sumathi *et al.*, 2007). The problem with MCDM here is that it involves a set of alternative allocation plans evaluated on the basis of multiple, conflicting and non commensurate criteria by several interest groups (Malczewski and Jackson, 2000).

Examination of the matrix of factor weights (Table 1) reveals a characterization of unique preferences with respect to the relative importance of criteria against which the alternative plans was evaluated. Thus, the ability of GIS to capture, store, retrieve and analyse data and MCDM's ability to combine the geographical data with decision makers preferences and evaluate them based on values of alternative decisions to arrive at the best alternative was cleared demonstrated. As seen here, two approaches of MCDM have been utilised, i.e., the multi objective approach and the multi attribute approach and the resultant maps are presented in Fig. 7 and 8.

To interpret and understand the map shown in Fig. 8 and to indicate areas most suitable, the map ws reclassed so as to give a value of 0 to all values from 0 to just <1 for unsuitable areas, a value of 1 to all values from 1 to just <100 as moderately suitable areas, a value of 2 to all values from 100 to just <150 for suitable areas and a value of 3 to all values from 150-255 for most suitable areas for waste disposal.

The location of the existing waste disposal sites in comparison with the final suitability map shows that most of the current sites were located conventionally (but with proper supervision). However, the current study has

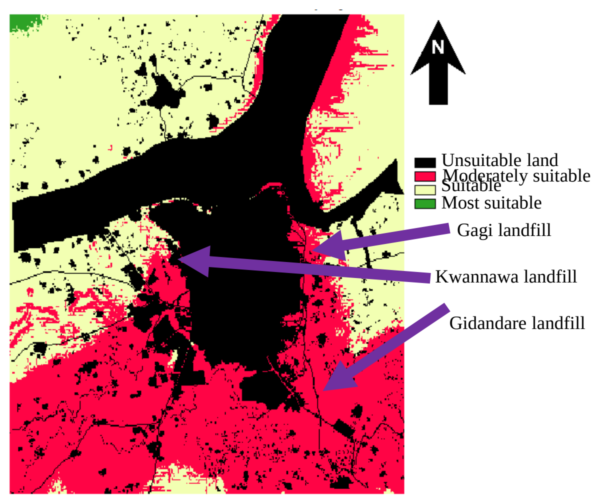

Fig. 8: The current location on the final suitability map reclassified to show unsuitable land, moderately suitable, suitable and most suitable land for waste disposal

shown that although criteria weights were assigned to the various datasets in the analysis so as to evaluate criterias based on their relative importance such weights do not apply to a specific factor but applied on a pixel by pixel basis to the factor scores as determined by their ranking and ordering them across the factors at each location (pixel) (Eastman, 2006). This is perhaps not surprising because they were assigned to the location's attribute value in decreasing order without considering from which criteria map the value came from (Malczewski, 2006). For example, order weight 1 was assigned to the lowest ranked factors, order weight 2 to the second ranked factor and so on. Accordingly, Fig. 8 shows the final suitability map reclassified to show a hierarchical techniques structure called Analytical Hierarchy Process (AHP) which was a technique utilised by both Eastman (2006) and Akbari *et al.* (2008) with the aim of selecting alternatives and rating criteria. However, in the AHP procedure alternatives were structured into a hierarchical framework which was constructed through pairwise comparison of individual judgments rather than prioritising the entire list of decisions and criteria simultaneously. Hence, this is just beyond depending on an automatic hierarchical classification but supplemented with a supervised classification (overseer) which took into account many issues regarding cost implications in landuse as well as risks to health hazards and environmental degradation around the study area. An examination of the map on Fig. 9 testified that this supervised classified map indicating the most suitable sites (at least for the three

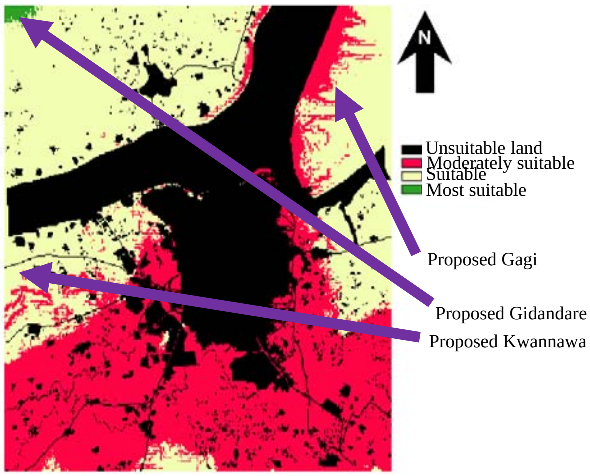

Fig. 9: Proposed new sites of disposal sites for the Gagi, Kwannawa and Gidandare

official dump site) around the Sokoto metropolis became a reality. In this regard, the compatibility of suitable sites with present and future land uses adjoining the site and the availability of sufficient soil for cover material had to be considered. It should be stressed here, that waste disposal site selection should take into consideration the distance of the site from residential, commercial, agricultural and industrial uses. Environmental and health considerations regarding odor, noise, contamination of water sources and air as well as other aesthetics are also vital. Accordingly, noise and fires can also become nuisances to public (A1-Bakri *et al*., 1988). On the other hand if waste disposal sites are located in close proximity to certain areas, their economic value will depreciate. Thus, land use suitability analysis therefore aims at identifying the most appropriate spatial pattern for future land uses according to specific requirements, preferences or predictors of some activity (Collins *et al*., 2001). Furthermore such analysis nowadays is one of the most widely used and GIS application in planning and management (Malczewski, 2006). For example, it was applied in agricultural, ecological and geological planning and management as well as urban, regional and environmental planning (Malczewski, 2006) and for suitability analysis in determining suitable urban green spaces using GIS for selecting suitable hospital sites (Vahidnia *et al*., 2009) and for suitability analysis in transportation planning. Because of its versatility in suitability analysis, MCDM can be extended to determining land for agricultural activities, recreational activities, industrial activities, etc.

Accessibility of a waste disposal sites from waste collection and generation points according to this study was another important criterion in the site selection. However, this criterion has its overtones regarding costs and benefits. The cost of transporting waste though important should not be the sole consideration because other considerations may override the cost of transportation. For example, a site far away from collection points may have the lowest impact on human health and the quality of air and water in the urban area. Therefore, the importance of both have to be weighed to determine the most important and thus, the reason for the ground truthing and subsequent supervised classification to finally arrive at results shown in Fig. 9.

From the proposed map on Fig. 9, it can be seen that the proposed new sites for the Gidandare landfill is the most suitable site for waste disposal. The proposed disposal sites for the Kwannawa and Gagi are sites located in suitable areas where there will be enough coverage and accessibility to the sites from all collection points in all parts of the metropolis.

Waste disposal sites should not in any way be located far away from roads no matter the distance from the urban area because of accessibility to sites. Trucks must not to travel far distances on unpaved or nonexistent roads. All these require not only the utilization of an automatic methodology or technique but should be supplemented with human judgement if a sustainable and environmentally friendlier environment is to be sought.

The advantage of this land suitability analysis in a GIS environment however is that it reduces cost and time of site selection and also provides a digital data bank for long term monitoring of otherprospective sites (Sumathi *et al*., 2007).

CONCLUSION

The study has illustrated that remotely data is an excellent source of information for environmental research, particularly in selecting suitable waste disposal sites (dumping sites) where the utilisation of MCDM as a decision support tool in a GIS environment enabled the selection of the most appropriate waste disposal sites around the Sokoto metropolis in Sokoto State, Nigeria. Indeed, the deplorable situation regarding the three existing waste disposal sites in the metropolis (Kwannawa, Gidan Dare and Gagi) posed a lot of dander in terms of risks to human health as well as environmental degradation. Not only are alternative sites to the existing ones sought through this analysis but other prospective alternative (additional) sites can also be discerned with the use of the MCDM technique in certain environments that have similar lithospheric and hydrospheric conditions like Sokoto state and environs.

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