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Multi-Criteria analysis of landfill site for industrial solid waste

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Abstract

Soon after the nation's independence, efforts were geared at increasing industrial activities to improve the socio-economic standing of the country. One of such bold attempts by private and some state initiatives at encouraging industrialization and urbanization in Nigeria, was the development of industrial layouts by the government of Ogun State, south western Nigeria, through its property and investment corporation. After a major break-through at an earlier industrial estate, the government felt the need to develop another industrial layout. However, dangers associated with industrial wastes in such an estate lay bear the necessity for an effective and environmental friendly method of industrial solid waste disposal landfill. Assessing a proposed site in the light of available minimum criteria was therefore the focus of the study. However the result of the study showed that the proposed site did not meet up with the stated requirement, hence a new place was searched for. Relying on the potentials of Geographic Information System (GIS) to proffer solutions to spatial problems involving multiple decision scenarios, the study called on the spatial database created for the work to generate a new optimal landfill site for the industrial estate. This work demonstrated the ability of geoinformation technology in helping to create a sustainable environment.

Keywords: GIS, Landfill, Waste, Site Analysis.

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Introduction

The various exploits made by man in all his industrial activities have, aside from increasing, to some extent, his wealth base, have also set in motion the gradual destruction of man and his future. Wastes; gaseous, solid and liquid, turned out in their tons, have become a menace threatening the most important and most distributed resource of man-the environment. Although industrialization is inevitable, various devastating ecological and human disasters which have continuously occurred over the last three decade or so implicate industries as major contributors to environmental degradation and pollution problems of various magnitudes (FEPA, 1989).

Industrial developments all over the world have emerged as a mixed blessing; while industries benefit a nation economically by providing jobs, developing infrastructures, producing tools and machinery useful for the raising of the standard of living of her citizenry, a lot of havoc is also done on the environment and the nation in general (Uwagbe, 2000). But while most of the initiators of the global industrial development have been able to cope successfully and somehow with the wastes from their industrial exploits, many industrially developing countries of the world, especially Africa, are still having swell time handling their by-products. For example, while industries and industrial estates are springing up in every nooks and cranny of the entity called Nigeria, there has been little success recorded in the area of selecting suitable sites for solid industrial waste.

While attempts have been made on creating solid waste dumpsites in industrial layouts, the facilities have been sited in several instances, especially in Nigeria without regards to standards. However, with the incursion of private and state agencies in the development of industrial estates, there is the need for a concerted effort at managing the various wastes generated by the various industries housed by these layouts. A sure way of doing this is to find the most suitable site for the dumping of these wastes, especially the solid parts using GIS.

GIS as a decision support tool, simplifies the search for suitable sites for a particular purpose because of its capability of spatial feature extraction and classification (Vitalis and Manoliadis, 2002). As a semi-structured process involving the consideration of several factors (Eldrandaly et al., 2003), only tools capable of analyzing and solving complex multi-decision based scenarios, such as GIS is useful. The spatial modeling capability of GIS which is a module for manipulating and analyzing spatial data to generate useful information for solving complex spatial problems, becomes useful in understanding relationships among geographic features that are considered in selecting optimal site for landfills.

Description of Study Area

One of the legendary attempts by private and some state initiatives at encouraging industrialization and urbanization in Nigeria, is the development of industrial layouts by the Ogun State Property and Investment Corporation (OPIC).The OPIC Lagos/Ibadan Expressway Industrial Estate is in Ogun State, a fast growing state in the southwestern part of Nigeria with a population of about 3.5 million people (NPC 2006). Lying within 06^0 30' N and 07^0 N and 02^0 45' and 04^0 30 E, the state is bounded on the west by the Republic of Benin, east by Ondo State, to the north by Oyo State and to the south by Lagos State. The success of the state on the Agbara-Igbesa industrial Estate of about 8,000 hectares, prompted OPIC to acquire the 20,020 hectares of land mainly to cater for residential and industrial activities. The estate has three schemes with the study area being the first Industrial zone. The various land uses that have been proposed for the Industrial Zone include, a recreational (central) park, commercial land use, alongside a Police Station, a Fire Station, two Petrol Station and of course the proposed landfill site. A settlement (Maba Village) also fall within the industrial zone which covers a total coverage area of about 2499.103542 km^2.

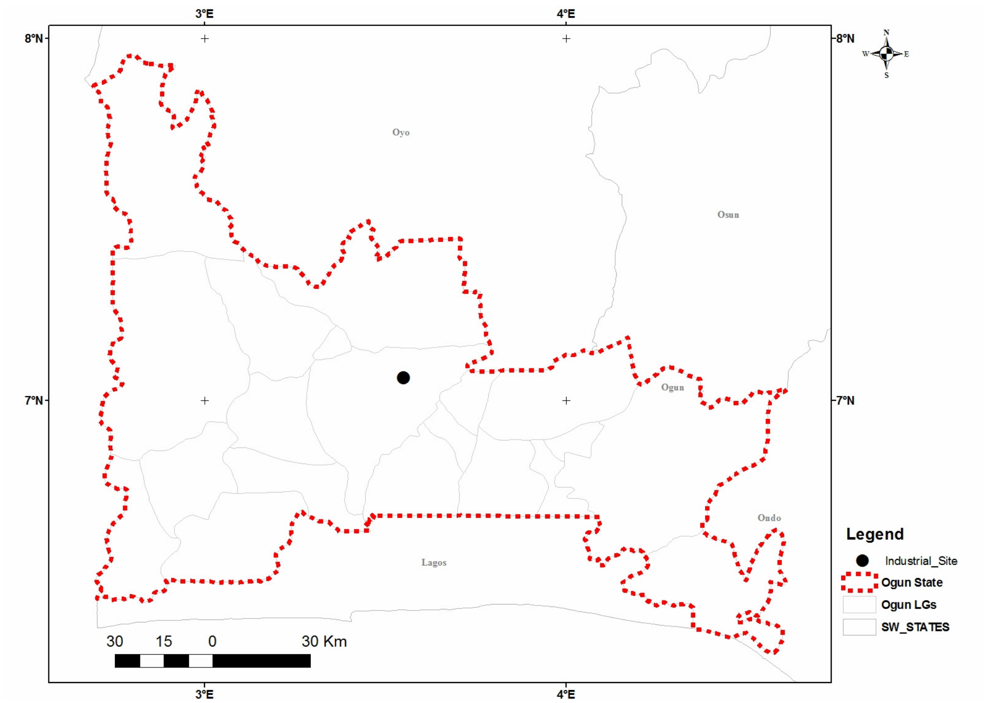

Fig. 1: Locational Map of the Study Area

Industrial Waste Classification and Management

Industries categorized as light, medium or heavy, have one thing in common and that is the generation of waste. Virtually all industrial and other man's activities generate waste which may directly or indirectly be harmful to man and his environment. Waste can be defined as useless, unused, unwanted or discarded materials (World Bank, 1982). They are also seen as "any undesirable or superfluous by-product, emission, residue or remainder of any process or activity, any matter, gaseous, liquid or solid or any combination thereof, originating from any residential, commercial or industrial area and which is discarded, accumulated or stored with the purpose of recycling or extracting usable product from such matter" (Government Notice no. 10, 1986). In this sense, waste refers to any material considered to be no longer useful and which may be dumped and thrown away.

Industrial wastes are large in number and they varied in magnitude and composition (Ademoroti, 1988). Solid (industrial) waste on its own may be defined as useless, unwanted or discarded materials arising from man's activities and which are not free flowing (WHO, 1971). Deductively therefore, solid industrial wastes relate to those unwanted and discarded materials generated from various industrial activities of man. They can be classified as either hazardous (toxic) or otherwise. Generally, solid industrial wastes include solid waste resulting from industrial processing and manufacturing operations such as food processing wastes, boiler house cinders, wood, plastic and metal scraps and shavings; lumber, roofing and sheeting scraps, rubble, broken concrete, plaster pipe, wire insulation wastes, explosives, radioactive materials, sludge etc. (Savas, 1979). Others include High-grade papers like computer paper, white paper ledger, Old Newspaper (ONP), corrugated cardboard, Aluminum, glass, Ferrous metals (Iron and steel), High-Density Polyethylene (HDPE), batteries of different compositions among others (FEPA, 1989).

Generally, waste management takes place in three main stages and these include: waste generation concerned with the generated wastes; their types, classes, physical components and chemical properties. As expected, the OPIC Lagos/Ibadan industrial estate is expected to house different groups of industries among which are agricultural chemical industries, automotive battery, food processing, iron and steel, metal working, plating and finishing industries, petrol chemical plastic and synthetic industries among others (OPIC Information Brochure).The table below shows the expected waste (by-product) common to industries expected in the industrial estate.

Table 1: Showing Various Industries, their waste types and components

Industry	**Waste**	**Chemical Constituent**
Agricultural Chemicals	High volume of gypsum especially from fertilizer producers.	Phosphate ($PO4^3$) Fluorides (F)
Automotive Battery	Defective battery casing and defective lead plates	PH, Iron, Cadmium, Nickel, Copper, Cobalt, Arsenic
Inorganic Chemicals	Sludges	Acetic acid, pH, Sulphate, Chlorides, Hydrochloric acid.
Iron And Steel	Flue dust, slags and sludges.	Ether soluble, Phenol, Cyanide (CN) NH^3 as N
Metal working, plating and furnishing	Sludges containing high heavy metals.	Acids, Cyanides, chromic acid.
Petrol-chemical	Oily chemical sludges, discarded packaging materials, Carbon black; polypropylene	Ammonia, Sulphide. Lead, Chromium (VI).
Plastic and Synthetic	Packaging materials, waste plastic products.	Zinc, Copper, Fluoride, Hydro-carbon
Pulp and Paper	Bark and fiber from paper, saw dust and clarifier, sludges	Hydrogen sulphides, Sulphur dioxides.
Textile mills	Sludges, textile wastes	COD Chromium (VI) Phenols, Sulphide, Coliform

Source: FEPA, 1989.

The second stage after the generation of the afore-mentioned wastes is their storage and collection and this is concerned with preparing the waste in a way suitable for collection and loading from the point of generation onto a vehicle for onward transfer to the waste disposal site. Before being finally disposed off by landfill method, the wastes are prepared in such a way to reduce their effect on the environment especially the land and groundwater bodies. Methods used for waste include:

- *Immobilization* - which are physical and chemical processes that reduce surface area of waste to minimize leaching.
- *Stabilization* - which is the conversion of waste from its original form to a physical and chemically more stable materials.
- *Solidification* - this involves the chemical reaction of waste with the solidification agent, mechanical isolation in a

protecting binding matrix, or a combination of chemical and physical processes.

- *Encapsulation* - this is used to coat wastes with impervious materials so that they do not contact their surroundings. (Oleghe, 2000).

The final stage in the handling of the generated industrial solid waste is its ultimate disposal. The various waste generated have to be catered for through disposal which is the removal of waste from human (physical) environment to a site (place) where it does not continue to constitute health hazards and, and have little or no impact on environmental quality (Oduntan, 2001). In trying to remove or discard waste from man's habitat, various management systems have been developed over the years, each with its own merits and demerits. Practices for collecting, processing and disposing of solid waste however vary widely, generally in accord with the nature of the waste stream and key environmental and economic features. It is as a matter of fact, a function of per capital income (Dashe, 2002). These methods include;

- ❖ Source Reduction – in which case the amount and /or toxicity of waste generated is reduced from origin.
- ❖ Recycling – this include collecting, re-processing, marketing and using of materials that were once considered trash.
- ❖ Waste Combustion – this is used to reduce the volume of the waste stream and to recover energy.
- ❖ Composting – this is waste treatment method that involves the use of microbial to decompose organic matter in waste.

All these methods of waste management however show that only a few portion of the waste are catered for, hence the adoption of land filling as one of the most suitable form of waste disposal.

Sanitary Landfill: a viable waste disposal method

The term land filling refers to the deposition of waste on land, whether it be the filling in of excavation or the creation of a landfill above grade, where the term 'fill' is used in the engineering sense (Waste Management Series, 1998). Despite the capacity and environmental concerns associated with landfill operations, every waste management system must still have access to a landfill. And to make it more environmentally friendly, the minimum requirements for landfill were established. Land filling is the only true disposal option especially of solid waste. It is therefore a necessary component of waste management, since all management options produce some residues that must be disposed off through land filling (FEPA, 1989).

Though it tends to have its own disadvantages, yet land filling is fast gaining ground as new regulatory control, design and operational practices, training and careful monitoring are making it more desirable. Proper landfill site selection is the fundamental step in sound waste disposal and the protection of the environment, public health and quality of life. Proper landfill site selection determines many of the subsequent steps in the landfill process, which, if properly implemented, should ensure against nuisances and adverse long-term effects (Ball 2005). A sustainable landfill is therefore aimed at disposing waste on land without creating nuisances or hazards to public health or safety, by;

- Utilizing all technologies including GIS to confine the waste to the smallest practical area.
- Reducing it to the smallest practical volume,
- Covering it with a layer of earth at the conclusion of each day's operation or at such more frequent intervals as may be necessary.

Two of the most important concept to be understood in the land disposal method of (solid) waste are:

- *Compaction*: this involves exerting some force on the waste to reduce the volume or space it occupies. This increases the capacity of the landfill and also reduces a number of nuisances such as flies, birds, odour and litter.
- *Leacheate:* this is an aqueous solution with a higher pollution potential, arising when water is permitted to percolate through decomposition of waste.

Leacheate can be categorized as;

* Sporadic (B^-), which results from abnormal circumstances such as excessively wet period of poor drainage.
* Significant (B+) resulting from climate and /or waste moisture content due to poor site selection (Institute of Waste Management, 1997).

Leacheate in the landfill site can be attributed to many factors including the water generated as by-product of refuse decomposition. However, the main contributing factor to leacheate quantity is the inflow of water from surface sources, such as rainfall. The production of leacheate due to rainfall is the result of several natural phenomenon as well as the method of operation of operation of the sanitary landfill (American Society of Civil Engineers, 1972). Landfill Leacheate contains contaminants including metals and organic chemicals, which, if not properly managed, have the potential to adversely affect valuable ground and surface water supplies, creating potentials impact to human health (Oduntan, 2001).

Landfill can be classified according to the waste type, size of waste stream or landfill operation and most importantly the potential for significant leacheate generation and need for leacheate management. Using waste type, landfill can be categorized as those for *General Waste (G)* including batteries, insecticides, weed killers, etc., *Hazardous Waste (H)* which has the potential, even in low concentrations, to have a significant adverse effect on public health and/or environment. Other landfill could be for inorganic wastes e.g. acids, alkalis, cyanide waste; *putrescible inorganic waste* from the production of edible oils, slaughter houses, tanneries, vegetable products etc. According to waste stream or landfill operation, landfill is classified by the daily rate of waste deposition, which, in turn, depends, on the size of the population served and this can be obtained using the MRD (Maximum Rate of Deposition) which is calculated by first obtaining the IRD (Initial Rate of Deposition).

Lastly, landfill can be classified in terms of potential for significant leacheate. Though it is acknowledge that any landfill is capable of generating leacheate at some stage in its life, this does not necessarily translate into a need for leacheate management (Institute of Waste Management, 1997).

FEPA (1991) highlighted basic design parameters for landfills if it is to be effective in the handling of the deposited waste. These structural conditions include some of the following construction properties:

* The landfill must have a liner designed, constructed and installed to prevent any migration of wastes to the adjacent soil, ground or surface water at any time during its active life.
* The liner may be constructed of materials that may allow waste to migrate into the liner (but not into the adjacent subsurface soil etc.)
* The construction material must have appropriate chemical properties and sufficient strength and thickness to prevent failure due to pressure gradients, physical contact with the waste or leacheate to which they are exposed.
* The facility must be constructed in such a way that any flow of waste into the fill can be immediately shut off in the event of linear failure (FEPA, 1991)

To meet a sanitary landfill, a set of minimum requirement has been established. These minimum requirements are standard by which environmentally acceptable waste disposal practices can be differentiated from the environmentally unacceptable ones (Waste Management Series, 1998). In practice, the minimum requirements for sanitary landfill consider the following fatal flaws:

* Non Proximity to significant surface water bodies, e.g. watercourses or dams, this is to avoid leacheate from contaminating the water bodies.
* Unstable areas which include fault zones, seismic zones and dolomitic or karst areas where sinkholes and subsidence are likely as this may open up the ground for easier penetration into ground water.
* Sensitive ecological and/or historical areas, including nature reserves and areas of ecological and cultural or historical significance
* Areas within 3,000m from an airport runway or within 500m of an airport boundary.
* Areas characterized by shallow bedrock with little soil cover.
* Area in close proximity to land uses which are incompatible with land filling e.g. health facilities, playground (Institute of Waste Management, 1997).

In therefore selecting a candidate site for landfill, the following requirements have to be considered:

(a) *Economic criteria* – this include;
- Availability of on-site soil to provide low cost cover.
- Land availability.
- Quality of on-site soil e.g. low permeability clayey soils on site which will reduce the cost of containment liners and leacheate control system.
- The distance of the landfill from the waste generation areas.
- The size of the landfill, which must cater for the disposal of the waste stream over at least the medium term to justify the capital expenditure.

(b) *Environmental criteria* -
- The distance of ground or surface water from the site
- The importance of the ground or surface water as water resources.
- The sensitivity of the receiving environment i.e. availability of a site already disturbed by man.
- Convenient slope that reduces the effect of run-off on the fill

(c) *Public Acceptance criteria* -
- Exposed sites with high visibility are not allowed.
- Distance of the site from other land uses.

- Conflict with other facilities especially reserves.
- Distance from any major road.

Methodology

To fully utilize GIS in the assessment and selection of a suitable landfill site, a spatial database which is a self-describing collection of integrated records that models the user's reality was designed. In this study, the three phases of database design were carried out namely; conceptual, logical and physical. For the conceptual phase of the spatial database, various entities, relationships and constraints were created at a high-level data model, i.e Entity Relation (ER) Diagram. A 2.5D vector data model which represents the real world using points, lines and polygons or area was adopted for the study. The entities identified for this work were parcels (polygon), road (line), existing village (polygon), stream (line), major roads (line), and a central park (polygon).

The logical phase on the other hand translates the conceptual maximization into something more practical, perhaps simply thought of as putting numerical values into tables of data, but avoiding the details of storage of data on physical media. For this work, the conceptual schemas defined at the conceptual stage were translated into the data model of a relational Database Management System (DBMS). To do this, some simple transformation rules were followed by defining the relational schema with the Data Definition Language (DDL). Lastly, for the physical phase, the actual database schema that holds the data values were defined.

The bulk of the data used for the study was secondary and they included geological map of the study obtained from the department of Geological Survey of Nigeria, topographical map of 1:2000 from OPIC Survey Department, layout map of the industrial zone 1 Scheme 1 at scale 1:2500, perimeter survey of the area also obtained from the Survey Department of OPIC. The data were later subjected to basic preprocessing like geo-referencing which was done to bring the scanned maps to their true earth location or position using the UTM coordinate system. A Digital Elevation Model (DTM) was also generated from series of x, y, and z coordinates obtained from the topo map of the area. Figure 2 shows the cartographic model which is a set of interacting, ordered map operations that act on raw data, as well as derived and intermediate map data, to simulate a spatial decision-making process (Michael, 1997) used in the study.

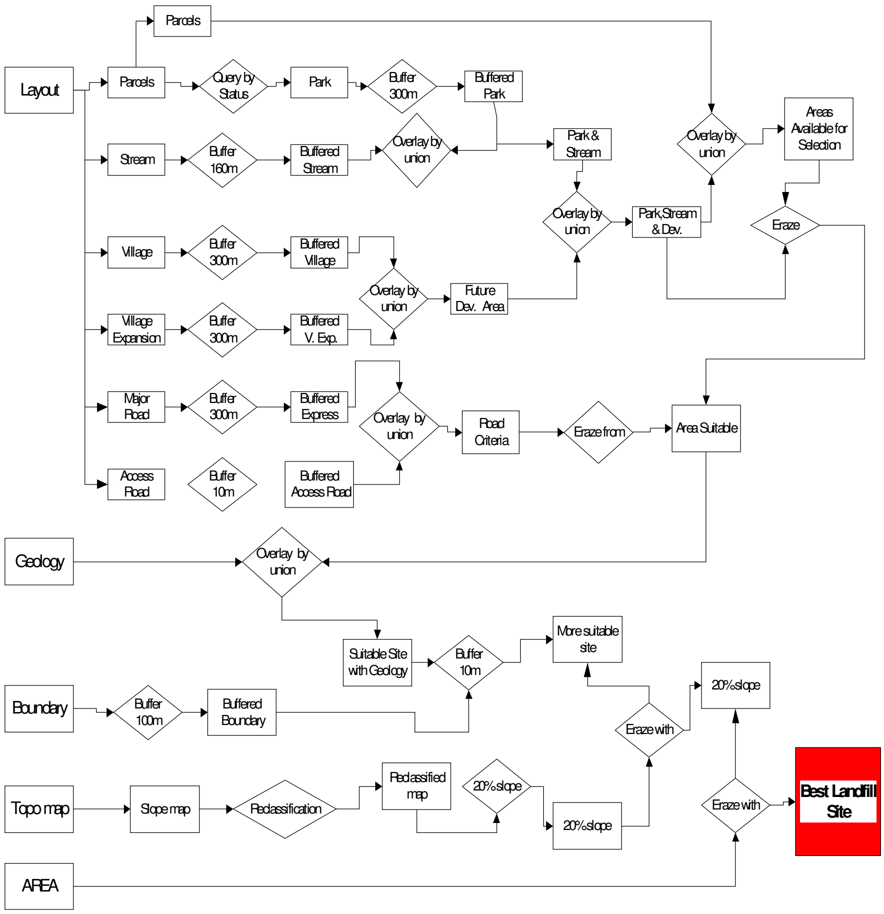

Figure 2: Cartographic Model developed for the study

Discussion of results

As stated earlier, selecting a landfill site requires that minimum conditions be met. Those conditions stated implicitly above were later explicitly stated in a more concrete terms below, taking into cognizance existing rules on landfill sites and prevailing situation in the study area (FEPA 1989).

i The site must be at a 160m distance from any water body (e.g. stream, rivers, bore-hole etc.

ii The site must be at least 300m away from all residential area.

iii The site must also be 300m meters from any major road.

iv A 300m distance is required from any reserve such as parks.

v The site must be 100m away from the boundary.

vi The site should not have a slope of more than 20% of the area of interest.

vii The site should have a size large enough to justify the capital expenditure of the landfill, say about an hectare of land.

Having established the criteria necessary for a sanitary landfill, the following spatial analysis were carried out on the datasets generated;

Spatial Search:- was done to bring out parcels demarcated as reserves (park) and those that meet the size (area) criteria for the landfill. The search was done using the query builder in the implementation software, by querying the attribute theme table of the parcels as stored in the spatial database of the study. The search was done as follow for the park:

Query Modelled :[([Status] = "Park"). Fig3(a) shows the result of the search to select the

reserve landuse in the area.

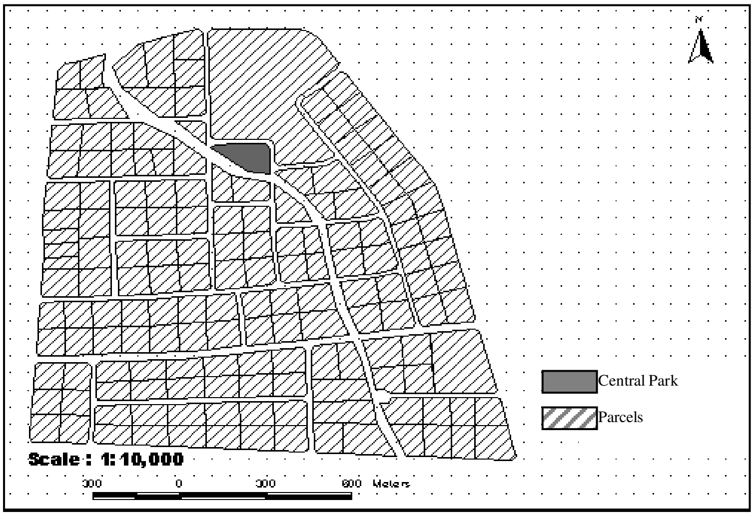

Fig 3(a): spatial search for the central park

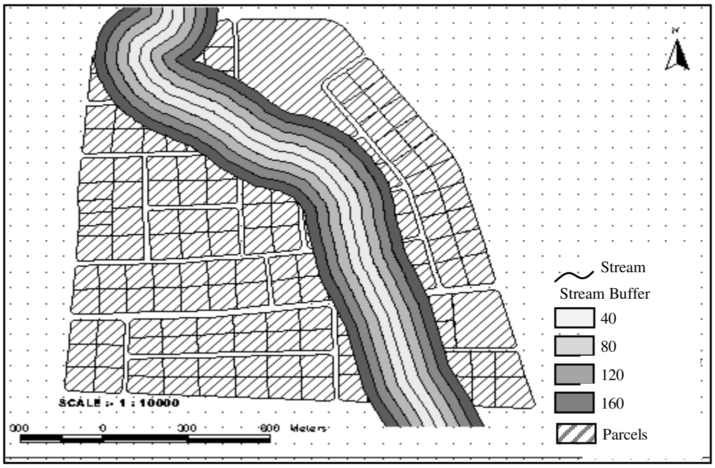

Fig. 3(b):Example of Multiple ring buffer

Buffer Generation: This is spatial function in which a zone of interest is created around a given feature or object and it was generated to demarcate areas not to be affected by the landfill. Some of the criteria set for the landfill require that the selected site be away from other certain other facilities. For instance, a 300m distance from residential areas and a 100m distance from the boundary is required. Buffers created in the work were generated in multiple rings to allow the system to be queried for lower buffer value than specified in the minimum requirements. For Example the stream passing through the study area was carried out with a 4-ring buffer at distance of 40m in between rings i.e. 160m in all (fig 3b).

Overlay Operations: This is a GIS analytical tool used to merge two themes to generate a new set of information. A number of themes were overlaid by union. For example the parcel-poly theme, which contains the topological parcels, was overlaid (by union) with the buffer of some other themes like the buffered stream, central park and its buffer etc. The results of all the buffer generation were erazed to give the plots that can be chosen as a landfill site. The result of this analysis generated from the composite map and the buffered stream.

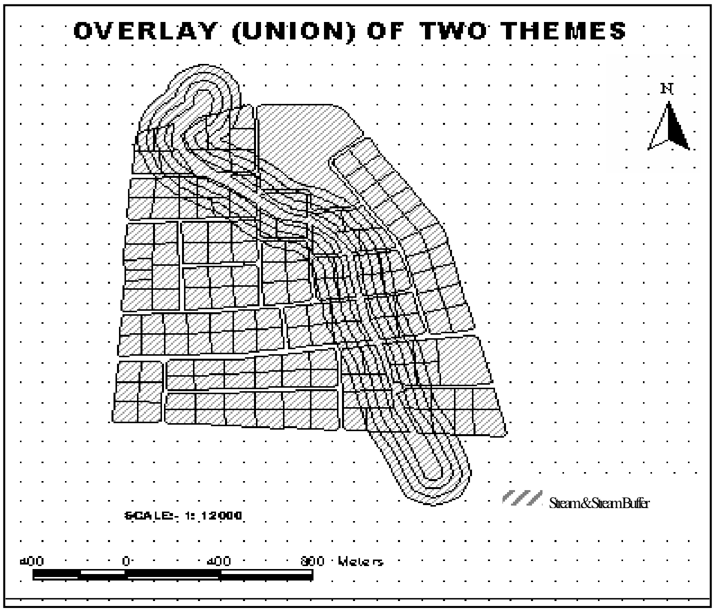

Fig 4(a) Overlay (union) of two themes

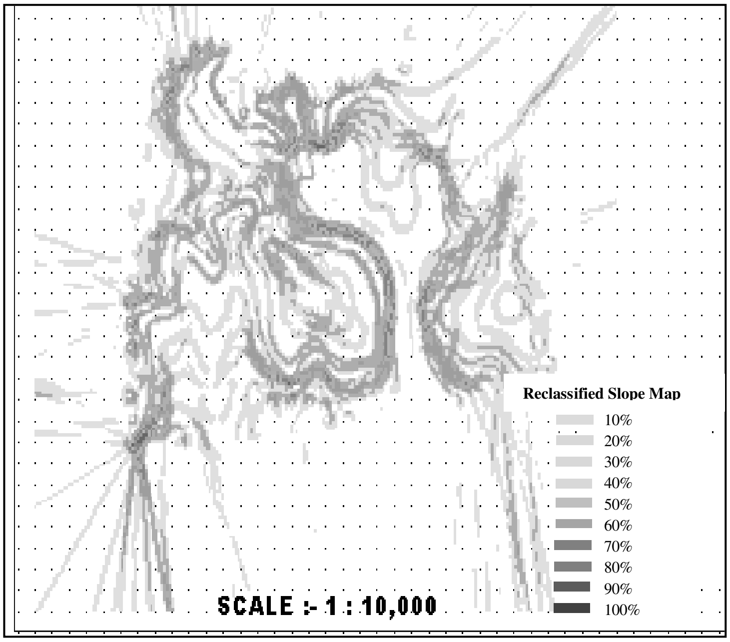

Fig 4(b) Reclassified map of the slope of the terrain

Reclassification:- This was used to reassign thematic value to the slope map of the industrial estate so that the 20% slope criterion could be separated from the entire surface. Fig. 4(b) shows the result of this analysis while fig. 5(a) shows parcels in the industrial estate that meet other criteria except the 20% slope requirement.

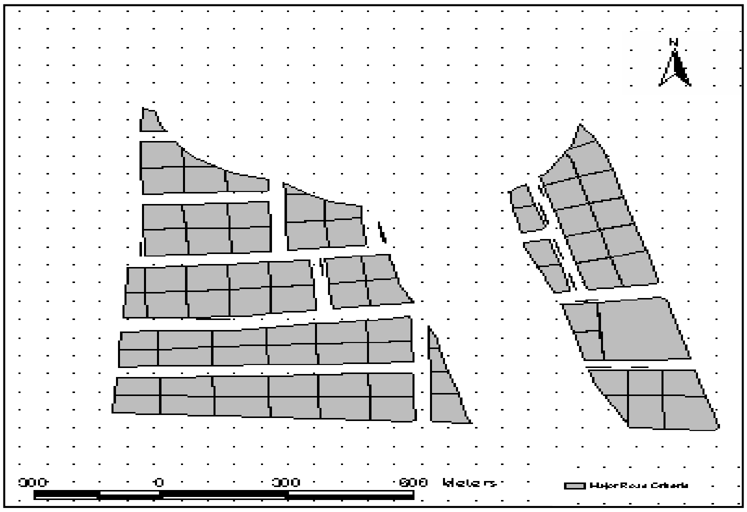

Fig 5(a) Parcels meeting other criteria save slope

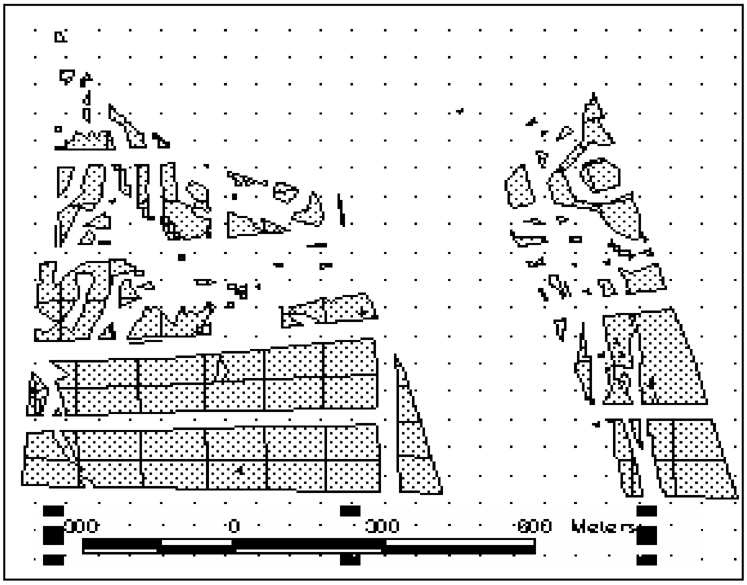

Fig 5(b) Parcels that meet slope criteria

One of the most important crux of this study is to evaluate the proposed landfill site against minimum standard and to site new optimal point where the proposed failed to meet up with the set of minimum criteria. To do this, the six criteria earlier discussed were considered and analyzed. The analyses revealed that the proposed site for the dumpsite does not meet the requirements. The only edge the site has over the rest is in terms of size as it meet the minimum 2-hectare requirement. However, when the 20% slope requirement was introduced, the proposed site fell short, in that some part of the plot was distorted with slope more than 20%. The implication of this is that the proposed site labeled P/R Depot in fig 6(a) will have to be jettisoned for a new site that will meet the minimum sanitary landfill requirement.

A new site was therefore sought for and the next biggest plot (9618 m^2) with no slope distortion and that met other minimum requirement was selected. Though this best site may not meet the size requirement, it has other advantages in that it can be annexed with adjoining plots to make up for the short coming it has in terms of size.

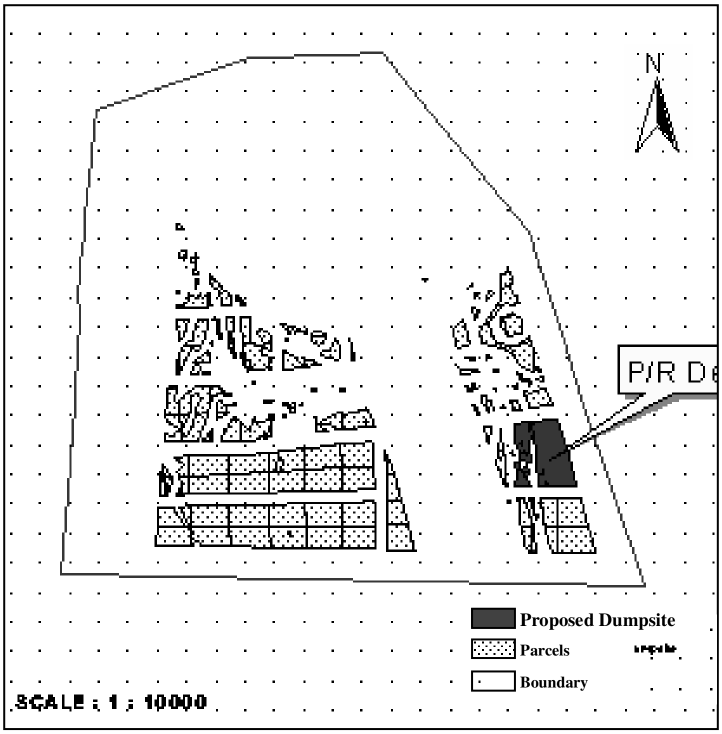

Fig 6(a) Overlay (union) of two themes

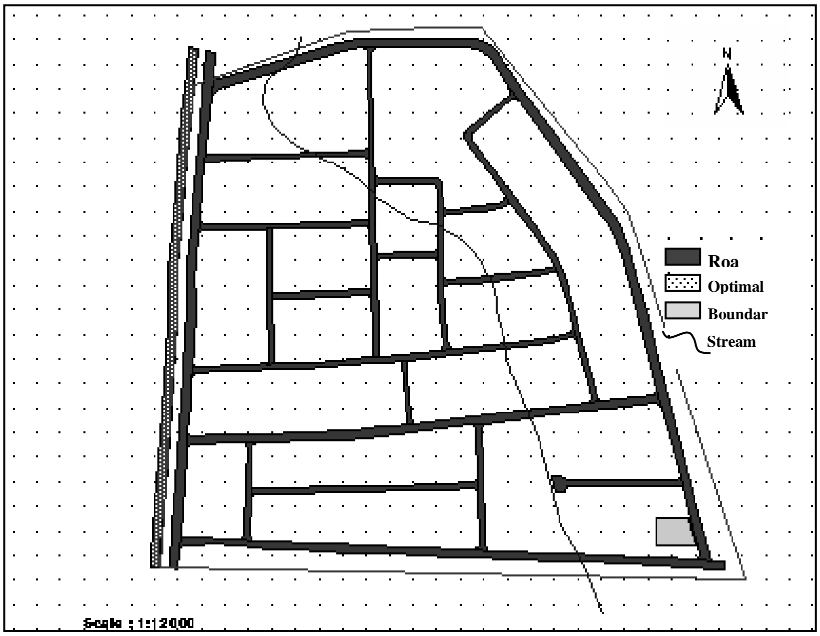

Fig 6(b) best Sanitary Landfill Site that fulfill all the Sanitary Landfill Criteria

Conclusion

The study, concerned with the assessment of a proposed landfill site for industrial solid waste was carried out first by establishing the minimum requirement for sanitary landfill and then using GIS to assess the proposed site in the light of these minimum requirement. Various analyses were carried out on the data or theme with much emphasis on the database created for the themes. After a number of analysis involving such analytical tools as buffer, reclassification, overlay (union), it was discovered that the proposed site fell short of the minimum requirement in terms of slope as the site has a distortion of more than 20% gradient, which generally is not too good for a landfill. And as specified in the objectives, a new site that met the minimum requirement was selected. Though the selected site does not meet up with the minimum 2-hectare requirement, it was so chosen because the slope criteria enjoy more prominence than the area criteria met by the distorted proposed site.

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