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LOCATING POTENTIAL LANDFILL SITES USING GEOGRAPHIC INFORMATION SYSTEMS

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ABSTRACT

Regulations and public opposition can make siting municipal solid waste landfills difficult. The siting of a landfill not only requires diverse geological, geotechnical, and environmental considerations, but also must satisfy legal locational restrictions and other social and cultural factors. In this article a Geographic Information System-based method has been presented that identifies potential landfill areas for preliminary assessment. The regulatory restrictions, area attributes, and site assessment criteria provided by experts and/or users have been taken into account. The proposed method has been demonstrated by applying it to a landfill site selection study for the Nilgiri block of Balasore district of Orissa in India.

INTRODUCTION

Although integrated solid waste management aims at utilizing a variety of technologies, such as reduction, recycling, recovery and incineration, in order to divert solid wastes from landfilling, a significant fraction of solid waste still remains for disposal in a landfill. The siting of a new landfill has become a critical environmental issue for most municipalities in the wake of limited availability of areas suitable for landfilling and increasing public resistance [1].

Usually a landfill cannot be sited within a certain distance of the following: lakes, ponds, rivers, wetlands, critical habitat areas, water supply wells, flood plains, highways, and airports. In addition, landfills are not allowed in critical habitat areas, wetlands, and areas in which potential for contamination of groundwater or surface water bodies exists. Hauling of waste is one of the high-cost items in landfill operations; landfills should be located near roads to reduce related costs. A site may be technically and economically feasible, yet may have to be abandoned due to heavy public opposition. Hence, a preliminary assessment of public opinion regarding all potential sites in the list of candidate sites is essential. In many instances, residents around a proposed site cooperate if the owner's representative listens to concerns of the area residents and considers those in designing and monitoring a site. Noise, dust, odor, increase in traffic volume and reduction in property value often concern the area residents more than the fear of groundwater contamination [2, 3].

The process of selecting a landfill site is complex and tedious, and requires extensive multidisciplinary data on topography, soils, land use, transportation, water use, hydrology particularly flood plains, geology, waste type, waste volume, landfill volume, available disposal options, recycling, and incineration options and targets [4-6].

A Geographic Information System (GIS) is a digital database management system designed to manage large volumes of spatially distributed data from a variety of sources [7]. It is ideal for preliminary site selection studies because it efficiently stores, retrieves, analyses, and displays information according to user-defined specifications [8, 9]. Thus, once a GIS database is developed, it can provide an efficient and affordable means of analyzing potential landfill site attributes [10-12].

In the present study, a GIS has been used to generate digital maps from topographical sheets, land use maps, slope maps, and soil maps; apply landfill siting criteria to the maps generated; and integrate the above maps to yield potential landfill sites.

STUDY AREA

The methodology proposed here for locating landfill sites using GIS is general-purpose and can be applied to any region. However, in the present study its application has been demonstrated by applying it to select potential landfill sites in Nilgiri area (Orissa, India) for disposing solid wastes of Baleswar town.

Nilgiri is one of the nineteen blocks of Balasore district in the state of Orissa, India and lies between $86°60^{1}$ to $86°85^{1}$ E longitude and $21°55^{1}$ to $21°79^{1}$ N latitude, covering about 311 km^2. The block is bounded on northwest by Kaptipada block of Mayurbhanja district, on the east and south by Remuna and Oupada blocks of Balasore district, respectively.

The area is mainly rolling plains rising and falling in gentle slopes and studded with innumerable rocky mounds and hills. It consists of open plains, well cultivated and well watered during rainy season by natural streams and rivers. Sona river is the major river of the area. It arises in the Simplipal hills, and after a tortuous course eastward through the area, falls into Budhabalanga. Other significant hill streams are the Ghagra and the Tangana. At present, Nilgiri block comprises of 147 revenue villages under 14 gram panchayats. Soil of the area is of laterite origin, which falls under the red soil group.

METHODOLOGY ADOPTED

The methodology adopted in this study is of progressive elimination. The sites are first eliminated by applying exclusionary criteria based on environmental regulations and mandates like forest areas, buffer zones around streams, water bodies, and settlements (Table 1). Obtained sites are further screened for proximity to roads, population density, and slope. Depending upon the required dimensions of the proposed landfill, the sites whose areas are more than the minimum area required are selected, and are, finally, analyzed for soil and land cost.

Data Sources

In the present study, topographic maps and area boundary maps on a 1:50,000 scale have been used. The land use and soil maps have been generated from IRS-1C remote sensed imageries, and the slope map from the contour information of topographic maps.

GIS DATABASE DEVELOPMENT

The above mentioned toposheets and area boundary map were digitized using a Contex FSS 8000 scanner and an IBM RISC 6000 based-image processing system. The GIS database was developed using a Silicon Graphics RX 5000 system equipped with ARC/INFO GIS software [13-16]. Digitized topographical and area maps along with land use, soil and slope maps in raster format were used for developing the following coverages for the landfill siting database:

Area Boundary Coverage

The area boundary map "vilgrid" in raster format was converted to vector format by GRIDLINE command and was named as NILGIRI1. It was then edited in ARCEDIT section. The edited coverage was cleaned using CLEAN command with poly option and moved to NILGIRI2.

Table 1. Typical Criteria Used in the Present Study

Type of Criterion	Attribute	Specifications
Exclusive	Wetlands	Sites falling within wetlands are avoided
	Critical habitat area	Sites falling within such areas are avoided
	Forest areas	Sites falling within forest areas and national parks are avoided
	Water bodies	A distance of 50 m has been maintained for the ponds and tanks which are meant for drinking purposes
	Streams	A distance of 200 m has been maintained from the streams
	Flood plain	No landfill within 100 year flood plain
	Airports	A distance of 3000 m from any airport has been maintained
	Residential areas	A distance of 100 m has been maintained from the residential areas
Non-Exclusive	Roads	The areas within 1000 m of roads
	Population density	The areas with population density less than or equal to 200
	Slope	Areas with slopes less than 40%
	Area	Area of the site should be at least 1 km^2

Land Use Coverage

"Landgrid" was converted to vector format in ARCEDIT section, using GRIDPOLY command, cleaned and moved to LANDUSE1.

Soil Coverage

"Soilgrid" was converted to vector format in ARCEDIT section, using GRIDPOLY command cleaned and moved to SOIL1.

Slope Coverage

"Slopegrid" was converted to vector format in ARCEDIT section, using GRIDPOLY command, cleaned and moved to SLOPE1.

Residential Areas Coverage

From the "landgrid," residential areas were extracted in GRID environment and converted to coverage with GRIDPOLY command, cleaned and moved to RESID1.

Water Coverage

From the "landgrid," waterbodies, tanks, and wells were extracted in GRID environment and converted to coverages with GRIDPOLY command, cleaned, and moved to WATER1.

Forest Coverage

From the "landgrid," forest areas were extracted in GRID environment and converted to coverage with GRIDPOLY command, cleaned, and moved to FOREST1.

Stream and Road Networks Coverage

From the "landgrid," streams and roads were extracted in GRID environment and converted to coverages with GRIDLINE command, cleaned and moved to STREAM1 and ROAD1, respectively.

The created coverages were co-registered with their respective real-world coordinates, so that there would be integrity between the different coverages. The attribute tables of all the created coverages were modified to hold all the possible information that would be needed during the analysis stage.

Figure 1 shows satellite image of Nilgiri Block. Figures 2, 3, and 4 show land use coverage, soil coverage, and slope coverage, respectively.

DERIVED DATABASE

Using the basic database created from maps, certain other information required for the project such as population density and buffer zones, was created, as explained below.

Population Density Coverage

The population density coverage was generated on the basis of the latest available (1991) population and area. Figure 5 shows the population density coverage for the study area.

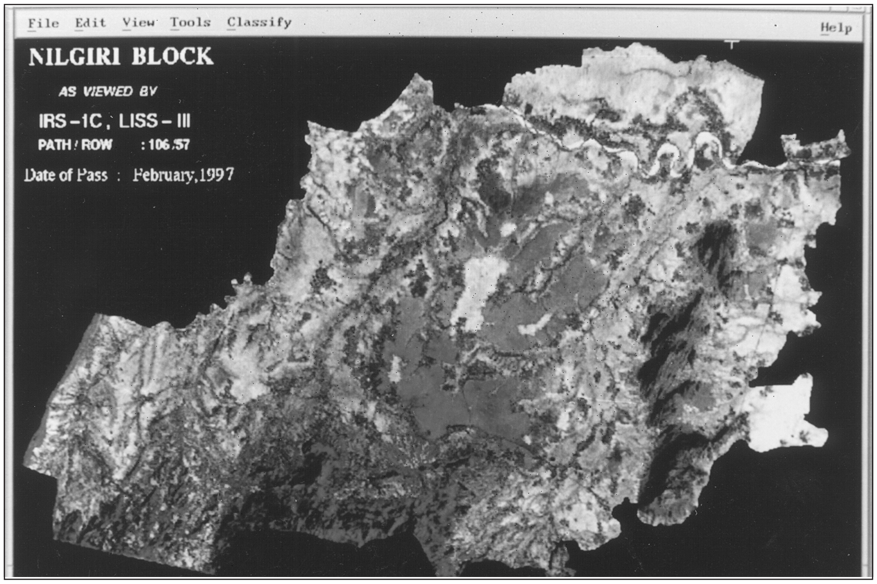

Figure 1. Satellite image of Nilgiri Area, Orissa, India.

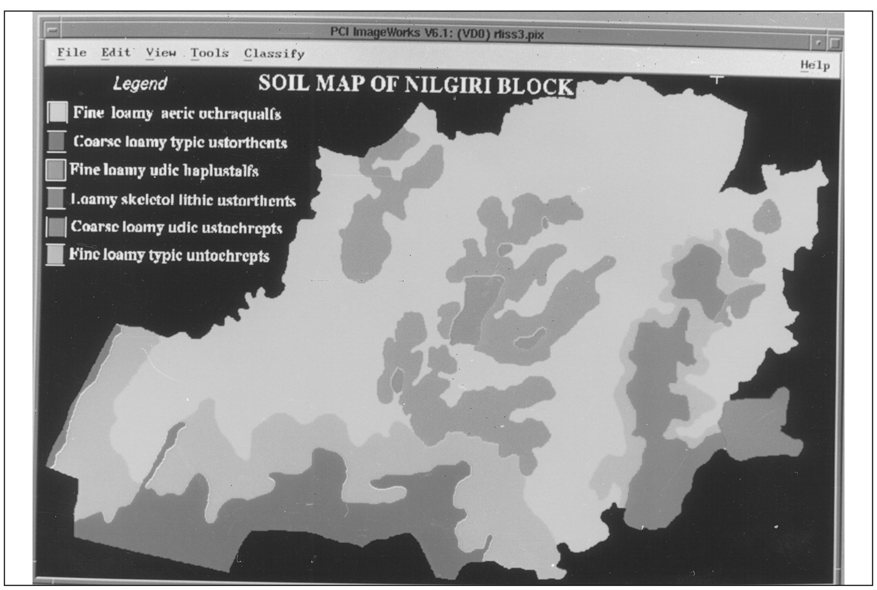

Figure 2. Land use coverage of the study area.

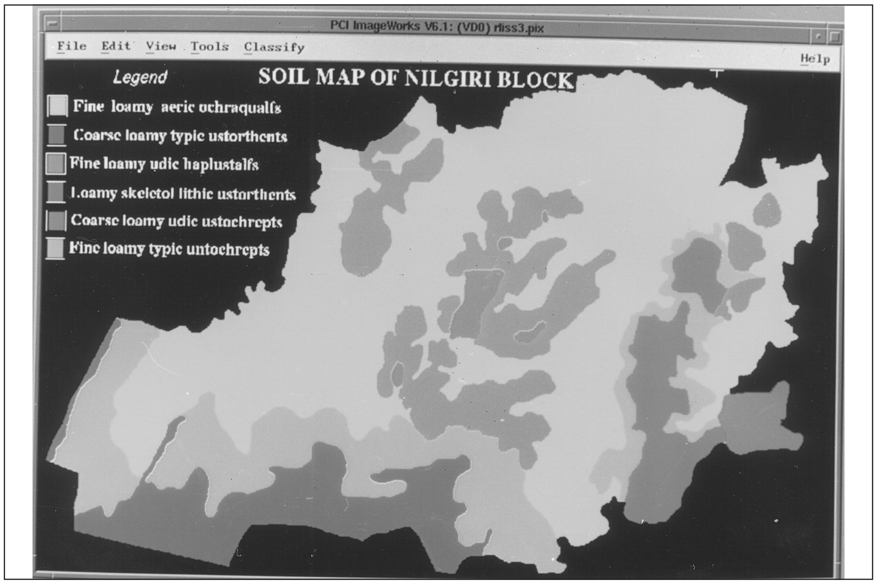

Figure 3. Soil coverage of the study area.

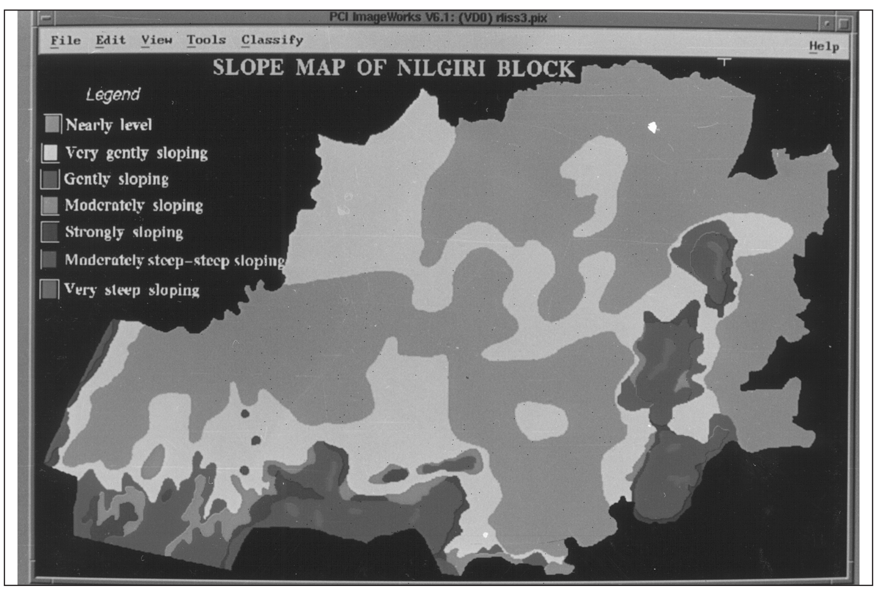

Figure 4. Slope coverage of the study area.

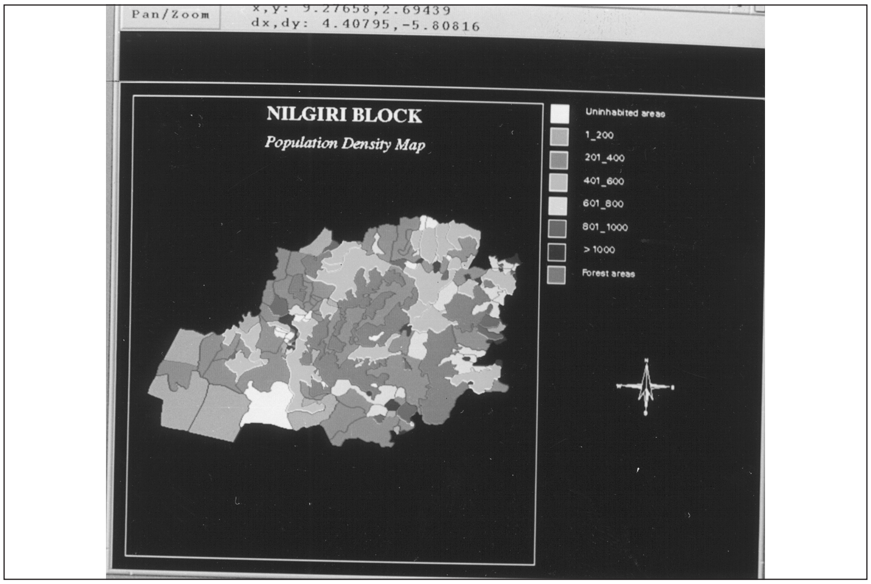

Figure 5. Population density coverage of the study area.

Generating Buffers

Generating buffer is the operation performed when the analysis requires identifying areas surrounding geographic features. The BUFFER command generates one or more polygons surrounding existing geographic features. This kind of polygon called a buffer or buffer zone, is used to determine spatial proximity.

For the present study, buffer zones were created around water tanks and wells, residential areas, streams, and roads, depending upon exclusionary and non-exclusionary criteria.

LANDFILL SITE ANALYSIS

At the analysis stage, the methodology adopted is that of progressive elimination based on certain exclusive and non-exclusive criteria governed by the environmental regulations and mandates.

Exclusive Criteria

First the exclusionary areas given below are excluded from the land use coverage.

Forest Boundary

About 12.8 percent of the study area was designated as forest inside which development activities could not take place due to environmental restrictions. Therefore, these areas were eliminated from the land use coverage, at the first instance.

Buffers

The sites falling within the buffer zones of tanks and wells, residential areas, and streams were also eliminated from the land use coverage. The areas thus left were analyzed for non-exclusionary criteria.

Non-Exclusionary Criteria

Slope Criterion

The landfill site requires more or less flat terrain. A threshold slope of 40 percent is chosen and the sites having slope less than 40 percent were only considered for further analysis.

Population Density Criterion

From the population density map, the areas with the population densities less than the average (i.e., 200) were selected for further analysis.

Proximity Analysis

The coverage obtained after elimination of the exclusive criteria was first intersected with the coverages containing selected slopes and population densities. The areas thus obtained were intersected with areas within the buffer distance of road coverage to reduce the transportation cost.

Area Criterion

The land area, or more important the space required, is primarily dependent upon the character and quantity of solid wastes, the efficiency of compaction of the fill and the desired life of the landfill. From the dimensions of the proposed landfill site, the minimum area required was 1 km^2. Sites with area greater than 1 km^2 were selected from the sites obtained after proximity analysis as potential landfill sites.

Developing a List of Potential Landfill Sites

By considering the availability of cover material and land cost, six potential landfill sites were obtained. Figure 6 shows the map containing these sites. The list of potential sites is given below in Table 2.

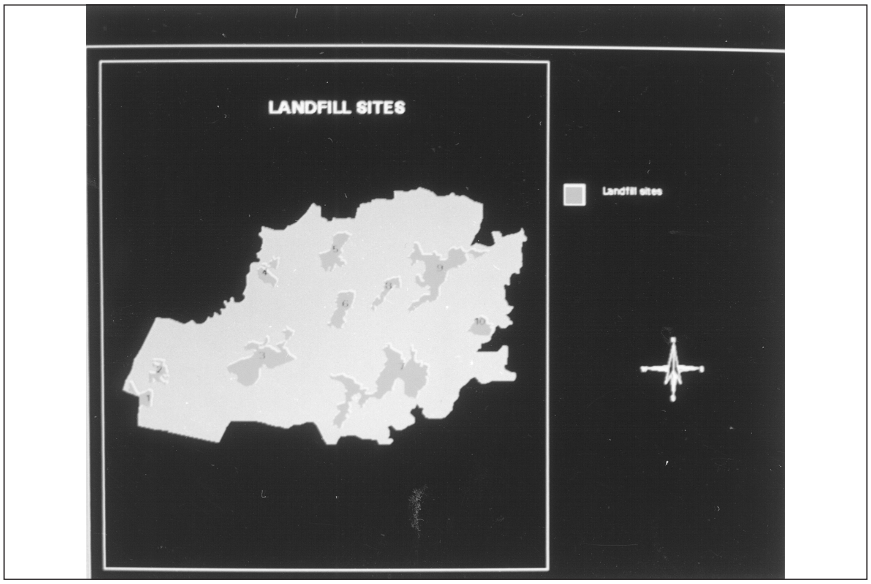

Figure 6. Map showing locations of various potential landfill sites.

Table 2. Potential Landfill Sites in Nilgiri Area

Sites	Area (km^2)	Slope (%)	Soil	Rank
1	2.18	5-10	Fine loamy	5
2	1.64	< 5	Coarse loamy	6
3	2.74	< 5	Fine loamy	3
4	6.31	< 5	Fine loamy	1
5	3.5	< 5	Fine loamy	2
6	2.2	< 5	Fine loamy	4

For the final site selection, three or more prime candidates should be initially considered and these were ranked on the basis of public acceptance. A report indicating conceptual design, geotechnical information, and discussion regarding locational criteria should be developed for each of the prime potential sites. These reports should then be discussed with the regulatory authority, the area residents, and the municipality in which the site is to be located to select a final site.

GIS tools can also be used to investigate the effect of parameters such as landfill size and general changes in exclusionary and non-exclusionary criteria. These investigations can provide valuable information concerning the spatial effects of changes in these parameters. For the present study, selection criteria are developed from existing landfilling rules and state regulations. However, criteria can be easily expanded to include other public concerns as well. GIS has the capability to include as many parameters as desired

CONCLUSIONS

The proposed approach for selecting potential landfill sites using GIS is straightforward and can be applied to any geographic area. The operation of the method has been demonstrated by applying it to the Nilgiri area of Balasore district of Orissa, India. Six sites were found to be suitable for landfilling in the study area. GIS technology can be put to effective use in narrowing areas of interest for potential landfill sites to a more limited number of sites. For the implementation of the outcome of this study in a real-world situation, a detailed study over two or three prime potential landfill sites alone will suffice. This will result in saving of precious time and money.

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