Geospatial strategy for sustainable management of municipal solid waste for growing urban environment

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Geospatial strategy for sustainable management of municipal solid waste for growing urban environment

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Abstract This paper presents the implementation of a Geospatial approach for improving the Municipal Solid Waste (MSW) disposal suitability site assessment in growing urban environment. The increasing trend of population growth and the absolute amounts of waste disposed of worldwide have increased substantially reflecting changes in consumption patterns, consequently worldwide. MSW is now a bigger problem than ever. Despite an increase in alternative techniques for disposing of waste, land-filling remains the primary means. In this context, the pressures and requirements placed on decision makers dealing with land-filling by government and society have increased, as they now have to make decisions taking into considerations environmental safety and economic practicality. The waste disposed by the municipal corporation in the Bhagalpur City (India) is thought to be different from the landfill waste where clearly scientific criterion for locating suitable disposal sites does not seem to exist. The location of disposal sites of Bhagalpur City represents the unconsciousness about the environmental and public health hazards arising from disposing of waste in improper location. Concerning about urban environment and health aspects of people, a good method of waste management and appropriate technologies needed for urban area of Bhagalpur city to improve this trend using Multi Criteria Geographical Information System and Remote Sensing for selection of suitable disposal sites. The purpose of GIS was to perform process to part restricted to highly suitable land followed by using chosen criteria. GIS modeling with overlay operation has been used to find the suitability site for MSW.

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Keywords Municipal Solid Waste · Suitable site · Geospatial approach · Weighted overlay · Multi Criteria · Urban Environment

Introduction

A high population growth rate and increasing per capita income have resulted in the generation of enormous MSW, posing a serious threat to environmental quality and human health, even India is not untouched by this threat. Solid waste disposal is one of the most troublesome logistic problems faced by society. Not only the quantity of solid waste has increased in past few years but also the available sites meeting stringent environmental requirements have been depleted. Landfill has become more difficult to implement because of its increasing cost, community opposition, and more restrictive regulations regarding the siting and operation of landfills (Gholamalifard et al. 2006). Growing urban regions face the problem of random landfill site due to shortage of land for waste disposal. Land is a finite and scarce resource that needs to be used wisely due to increasing pressure from developmental growth of the population need for housing and commercial purposes. Most of the landfill sites in region are disposed off randomly which has harmful impacts nature, human beings, and aquatic creatures. The ultimate destination of the solid waste is the landfill which needs to be at a suitable site, which is cost-effective, at transportable place and environmental friendly. RS and GIS have been helpful in the allocation of the suitable site for solid waste. The main parameters affecting the quantity and composition of the MSW generated are population growth and increased living standard of the people (Daskalopoulos et al. 1998). Because MSW arises as a direct consequence of human activities, population has been considered as the first major parameter determining the amount of waste generated. The increase in solid waste generation is attributed to changes in lifestyles of the people in the last 50 years (McLain 1995).Municipal solid waste management has thus become a major issue of concern for many nations, especially as populations increase (Bartone 2000). In some countries (e.g., US and EU), there is legislation that restricts the disposal of organic matter in landfill sites in order to decrease the greenhouse gas emission (European Commission Final Report 2009). The Directive 99/31/EC defines a reduction to 35% of the total biodegradable waste going to landfills until 2016 in order to reduce carbon dioxide and methane emissions.

Vector GIS has been used to identify landfill sites (Basagaoglu et al. 1997), solid waste disposal sites in the Philippines (Cruz 1993), and animal waste application sites in Australia (Basnet et al. 2000, 2001). Kallali et al. (2007) focused that GIS and expert knowledge are used as a decision support system to determine adequate potential soil aquifer treatment sites for groundwater recharge of aquifer. These sites are identified using a single-objective multi-criteria analysis (Chang et al. 2008). All criteria selected are assumed to be constraints for site (Kallali et al. 2007). Ratnapriya and De Silva (2009) determined the most suitable locations for putting up the treatment plants for non-point source pollutants using GIS thematic maps of stream characteristics, land use and vegetation cover and socio-economic characteristics with DTM. In recent years, Geospatial technology have been widely used for the allocation of sites for *wastewater* treatment plant suitability (Gemitzi et al. 2007; Finn et al. 2006; Gilliland and Potter 2007; Zhao et al. 2009; Kallali et al. 2007; Huffmeyer et al. 2009) and also efficiently used for assessment of land consumption rate with increasing rate of population growth (Sharma et al. 2011). Ribeiro et al. (2010) worked to find suitable area for bio-solids storage. They defined a sludge application index using GIS to produce land-use suitability maps, which can be useful for sludge management.

Current research is focused to allocate the best suitable site for municipal solid waste disposal in Bhagalpur region with the use of advanced Geospatial techniques. While locating the most suitable site, there would be certain factor which would be taken into account (Chang et al. 2008). The overall criterion as per the current study for municipal solid waste management in Bhagalpur region is established for proper planning at root level. Purpose of this research is to make people aware and be concerned about the planned way rather than unplanned, haphazard disposal of the MSW in city. Improper disposal is an important aspect to taken in to consideration as it increases environmental degradation, pollution and foul smell in the surrounding area. Suitable site for MSW disposal may be helpful for policy makers to give proper services to people at low-cost and in efficient timing. This will help them to meet the future requirements and solve the problems related to MSW disposal. Landscape protection and conservation of the natural resources in the vicinity of city are also important points in the decision MSW selection sites.

Current status of Municipal authority in study area

Municipal solid waste management is one of the major problems facing city planners all over the world. The problem is especially severe in most developing country cities where increased urbanization, poor planning, and lack of adequate resources contribute to the poor state of municipal solid waste management. In Bhagalpur city, the waste management is also facing problem due to lack of proper disposal of the municipal solid waste. Thus, by having a suitable site for waste disposal in this region, the problem of disposal of MSW at suitable site can be solved. The problem is compounded as many region of the city continue to urbanize rapidly. For instance, 18% is the urban population ratio of total population in 1991, and in 2001, this ratio increases to 19%.

Moreover, in Bhagalpur, the growth rate of urban population is nearly 2% which causes a tremendous contribution in solid waste generation. Although government does spend a part of municipal revenues on waste management, they are often unable to keep pace with the scope of the problem. Bhagalpur municipality serves 51 wards in its range. The municipality collects the waste form 21 points regularly and weekly from 10 points in its limit. The Bhagalpur Nagar Nigam disposes the MSW at any place which it found suitable for disposal. MSW disposals by Nagar Nigam at Champanagar, nearby Andheri river and Kalighat, nearby bank of River Ganga causing nuisance. Moreover, Jawaharlal Nehru Medical College and hospital at Kalighat often dump their biomedical waste nearby bank of Ganga hampering the conservation strategy of dolphins (known as Sons) by government. It causes problems to the dolphins as water carry away the MSW and biomedical wastes as well as chemicals which are soluble in water.

Current land filling sites are located at Kalighat and Champanagar region which is not in the condition to accommodate such tremendous amount of waste. Many problems are arising such as leachate percolation, foul smell, pollution etc. in that area. Moreover, its location is nearby the bank of pious Ganga River, and the above problems also create havoc to river inhabitants like dolphins (sons of the Ganga River, as called there). This is threatening the life and habitat of dolphins and thus, the conservation strategies by the government for protection of these mammals are worthless.

Geographical description of the study area

The study area is Bhagalpur district, Bihar state having spatial extent between 25°09′–25°18′ N and 86°51′–87°07′ E covering approximately 434.40 km^2. The study area is located in the plains of *Ganga* river basin at a height of 42.97 m above mean sea level (MSL). The population of the district as per 2001 census was 2.43 million and the density of population was 946/km^2. Study area is flood prone particularly the South Eastern and Middle Eastern part during rainy seasons. The mean maximum temperature and mean minimum temperature of the region corresponds to 38.6°C and 11.8°C, respectively. The average rainfall in the region is 1,078 mm.

Materials and methodology

The satellite data used in the study includes merged data of IRS-P6 LISS IV and Cartosat-1(IRS-P5) of year 2008. Ground truth data was collected in the month of November 2008 and January 2009 for visual interpretation and map generation with the help of global positioning system in the form of latitude and longitude that represent the accurate location. The overall methodology adopted for this research is summarised in Fig. 1. The methodology adopted for study utilises spatial analyst tools in Arc GIS environment with distance, weithage overlay features. Spatial analyst is used for the overall study with weighted overlay analysis. The data used in the study includes the raster form (.img) which has been resolution merged together (2.5 m spatial resolution of Cartosat-1and 5.8 m spatial resolution of LISS IV). The resolution merged image acquire the properties of both dataset like high spatial resolution of 2.5 m of Cartosat-1 and multispectral characteristics of LISS IV Imagery. There after, the work is carried out in Arc GIS environment with vector format (.shp) for digitization of the thematic maps as well as preparation of Land use/land cover map at the scale of 1:10,000. The land use/land cover map was created which is shown in Fig. 2. The data collected at the site include GPS points, field photographs and secondary data sources provided by municipal authority.

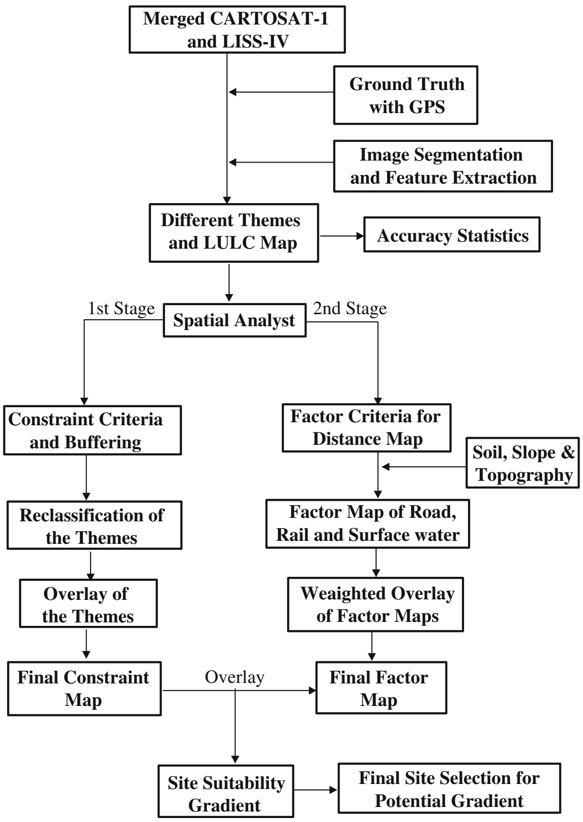

Fig. 1 Methodology adopted in the study

The municipal boundary as well as the information regarding the collection of the solid waste was procured from 21different sites.

Generally, factors that must be considered in evaluating potential sites for the long-term disposal of solid waste include distance from main urban area, location restrictions, available land area, site access facility, soil conditions and topography, surface water hydrology, local environmental conditions, and potential ultimate uses for the completed sites. The allocation of suitable site for municipal solid waste disposal using geospatial approach requires primarily inclusion of areas (nearby road, vacant land, and fallow land) favorable for suitable site and exclusion of areas (protected forest, waterlogged and sandy area) unsuitable or unfavorable for waste disposal. The overall criteria mainly based upon four factors i.e., technical (slope, road, rail, soil, and land use patterns), environmental (water bodies, waterlogged, marshy, sandy, and protected forest), social (population, distance from urban agglomeration), and political restrictions (administrative boundary of the study region). Suitable site selection in areas of outstanding natural or cultural beauty, as well as in waterlogged area is forbidden. Due to data constraints, Twumasi (2005) used topography, hydrology, cover materials, existing housing, and land development (roads, etc.) of the area as guides to site selection. Criteria were specified to assume that disposal site would be outside the buffer zone of the water bodies, forested areas, roads, and existing built-up area. Thus the criteria depend on the knowledge based and vary from region to region. These criteria are illustrated in Table 1.

The stages in the study must be according to assumed criteria which were identified by the integrated geospatial approach along with thematic maps. The work was carried out using the software's *Erdas Imagine 9.1*, *Arc GIS 9.2* and the *Arc Catalog/Arc Map* applications for the following tasks i.e. Georeferencing, resolution merging, construction of database layers, integration of spatial and non-spatial data etc. The methodology provides evidence for model that is utilized to determine the optimal disposal site. Data acquisition in terms of data availability is considered as it is of prime importance when using GIS. The technical approach was also employed to produce suitability maps emphasizing "suitable" geographic areas resulting from weighted and combined map layers based on established criteria. The selection of the suitable site is predicted using Geospatial techniques which include the reclassification and index overlay models. The technical approach employed to produce suitability map emphasizing "suitable" area resulting from weighted and combined map layers. The GPS and ground truth data collected from the sites were used to validate land use land cover classification. Based on the above collected information from field visits, the following tasks were developed i.e. Conversion of information from analogue to digital, spatial analysis and construction of the thematic maps, generation of land use/land cover map by visual interpretation and validated with field data and GPS points, establishment of criteria for solid waste disposal and finally generation of site suitability map.

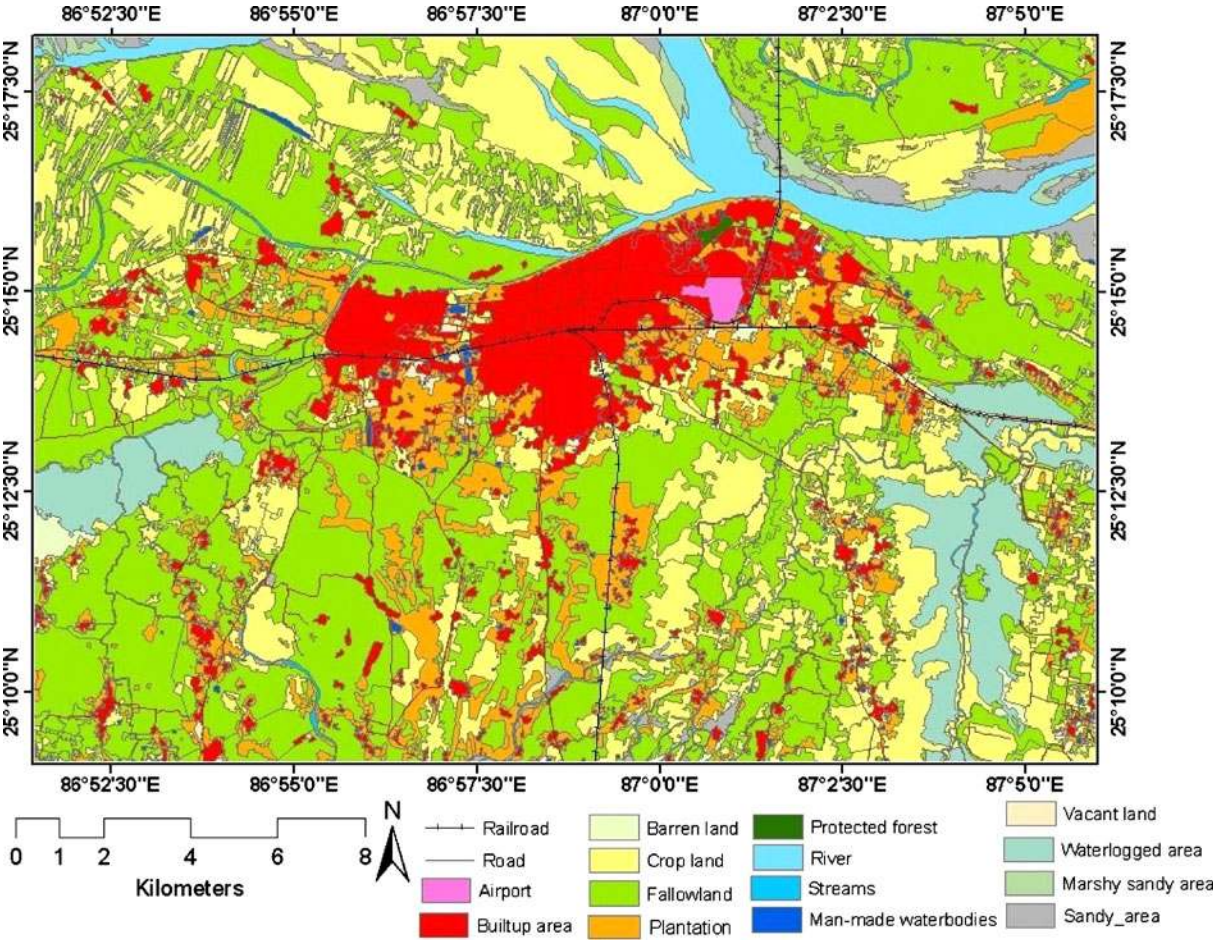

Fig. 2 Land use/land cover map of the study area

Table 1 Criteria to locate suitable site for waste disposal

No	Criteria	Sub criteria	Buffer zone
1	Technical criteria	Road	500 m
		Rail	500 m
		Slope	0–12%
2	Environmental constraint	Surface Water	300 m
		Sandy Area	Restricted
		Waterlogged Area	Restricted
		Protected Forest	Restricted
		Cropland	Restricted
3	Social	Land use land cover patterns	Future use of urban dynamics change
		Population & distance from urban agglomeration	Away
		Settlement (Urban)	6 km (in two rings)
4	Political constraint	Administrative boundary	Within reach

Results and discussions

Land use/land cover mapping

Land use/land cover map of the study area has been prepared using visual interpretation integrated with ground truth investigations (Fig. 2). This allows easy interpretation of the land use and features. A comprehensive visual interpretation on satellite imageries were carried out and the discrimination of the various Land Use/Land Cover was done manually. Total 14 classes were allocated in the Land Use/Land Cover map. Out of 14 classes, Fallow Land covers maximum area 167.58 km^2 followed by Cropland 114.72 km^2, Plantations 46.40 km^2, and Built-up area covered 32.02 km^2. Figure 3 shows the spatial extent (in square kilometres) of the land use features and their percentage in total land use classification maps.

This classification gave a better choice of interpretation and allocation of actual classes for the vast area of interest. For the purpose of solid waste disposal at proper place, the knowledge of soil type should be required by the management. The soil map was prepared in reference with the NBSS & LUP, Nagpur (National Bureau of Soil Survey and Land Use Planning; Fig. 4). The Bhagalpur is mostly covered by the alluvial soil based on texture of two types: fine alluvial and fine loamy alluvial soil. The study area is mostly flood prone and eastern region is waterlogged area which remains for almost whole year. The land use and land cover gives the idea about the places which can be extended as urban region and further utilization of land resources. The growing urban region place burden on development and people moved towards the outskirts of the city for better living in an open space away from the densely populated area. It is suggested that the rate at which new lands were acquired for built-up development is too high for Bhagalpur city. This situation will have negative implications in the urban region because of the associated problems of crowdedness and increased amount of solid waste management. Thus, land use map is most important criteria for the site suitability for MSW disposal. Overall accuracy for LULC maps were achieved 89.36% and kappa statistics corresponding to 0.84.

Slope map

Slope is a relevant factor for suitable landfill site selection, given that an area is an important consideration for excavation. Kao and Lin (1996) have suggested that the appropriate slope for constructing a landfill is about 8–12% because too steep of a slope would make it difficult to construct and maintain and too flat of a slope would affect the runoff drainage. Slopes above 12% created high runoff rates for precipitation. With higher runoff rate and decreased infiltration, contaminants are able to travel greater distances from the containment area. A lower slope also facilitates the construction of the site to be much

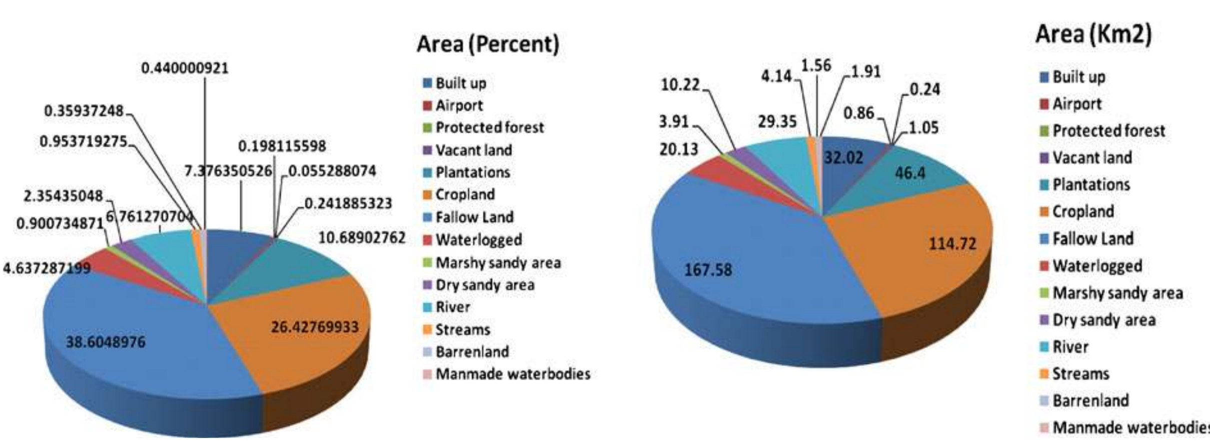

Fig. 3 Land use distribution (area and percent, respectively)

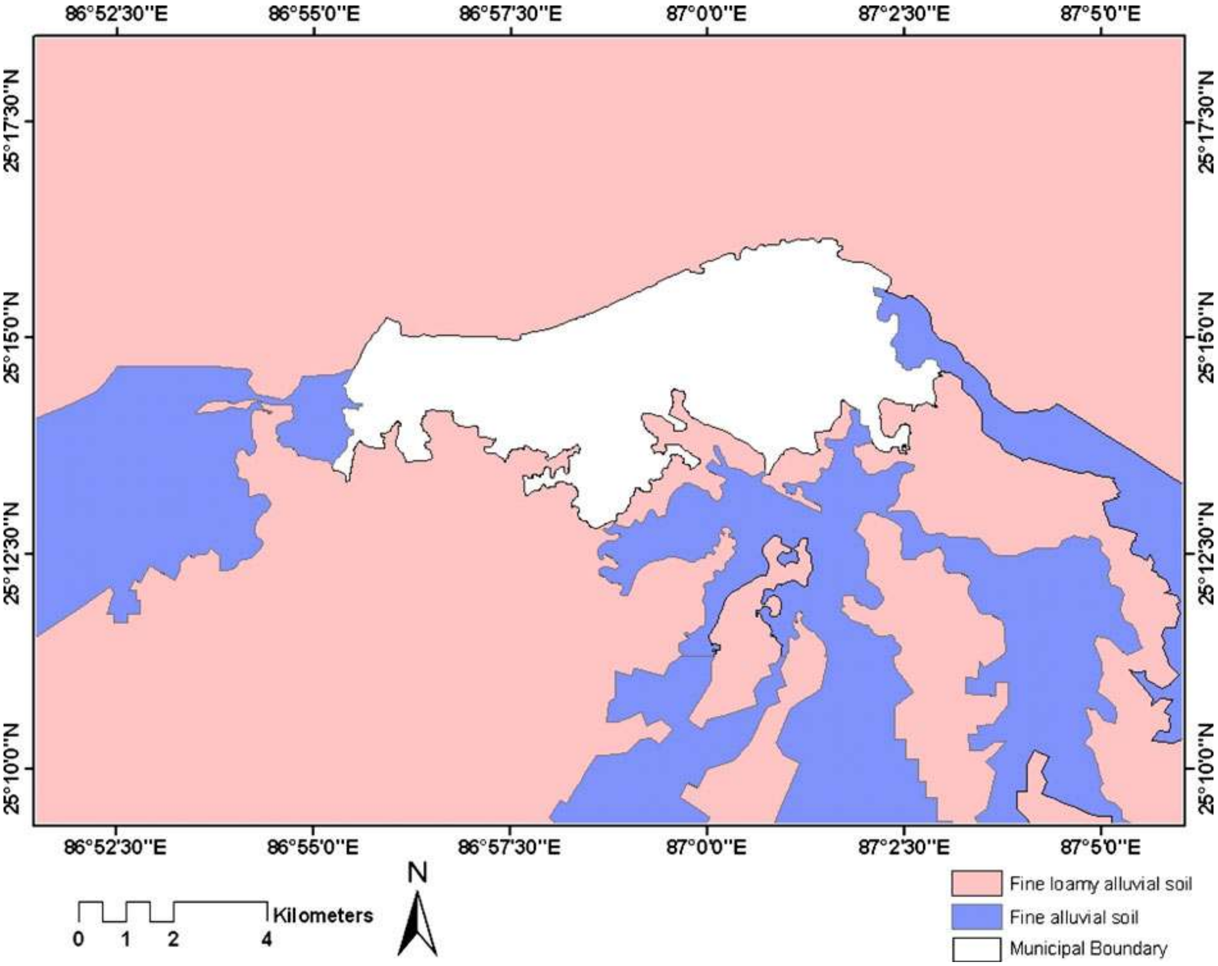

Fig. 4 Soil map of Bhagalpur (source: NBSSLUP, Nagpur)

easier and with lower costs (Atkinson 1995). The best slope chosen for the development of a landfill is between 0% and 12%. Furthermore, the slope map of Bhagalpur area was almost comprises of low gradient due to considerably flat terrain.

Buffer distance map

Buffer zones are created for making binary maps and then reclassified to two classes, namely zero (for non-suitable area) and one (for suitable area) classes. GIS tools were used to create buffer zones corresponding to specific criteria for road, rail, water bodies, and urban settlement. These buffers were created keeping in mind the accessibility, transportation cost, environmental concern, and distance from urban agglomeration. These buffers were incorporated according to region where the study was conducted as criteria differ from plain region to elevated regions. Buffer created for road and rail to ease access routes to the disposal site. Likewise for water bodies, buffer created to prevent the environmental pollution from leaching. Proximity to municipal limit allows regular and easy transportation of waste up to site. Some regions classified as restricted which were not included during the all GIS operations such as protected forest, airport, and agricultural area.

Reclassified map

Each map layer is to be ranked by how suitable it is as a location for a new suitable site. However, in order to be able to combine them, a common scale (for example, 0–1) giving higher values (scores) to more suitable attributes, is usually assigned to each class, using "Reclassify" option in spatial analyst. The layers generated in this step, was used in Index overlay integration method.

Constraint maps

Constraint (binary) maps are used to distinguish between lands that are suitable or restricted for disposal site. The constraint maps were produced by merging each individual theme containing only two classes represented by 1s (for suitable land) and 0s (for unsuitable land). Selecting a suitable site with respect to road, railway network or water bodies were based on the assumed criteria. The assumed criteria for the municipal boundary limit for disposal was also considered to prevent political restrictions as shown in Fig. 5. Selecting site close to a road or rail network would help reduce costs related to transportation and access to the site. To achieve this, the major roads and rail network thematic layers were re-classified to make sure that site is not located directly on the road. As a result road/rail network were given a 0 value and all other areas were given a 1. The constraint maps of road and rail network were shown in Fig. 6. The surface water (rivers, streams, waterlogged area, and manmade water bodies like ponds) layers were constructed in order to create surface water constraint map as shown in Fig. 6 with buffer zone around since they were

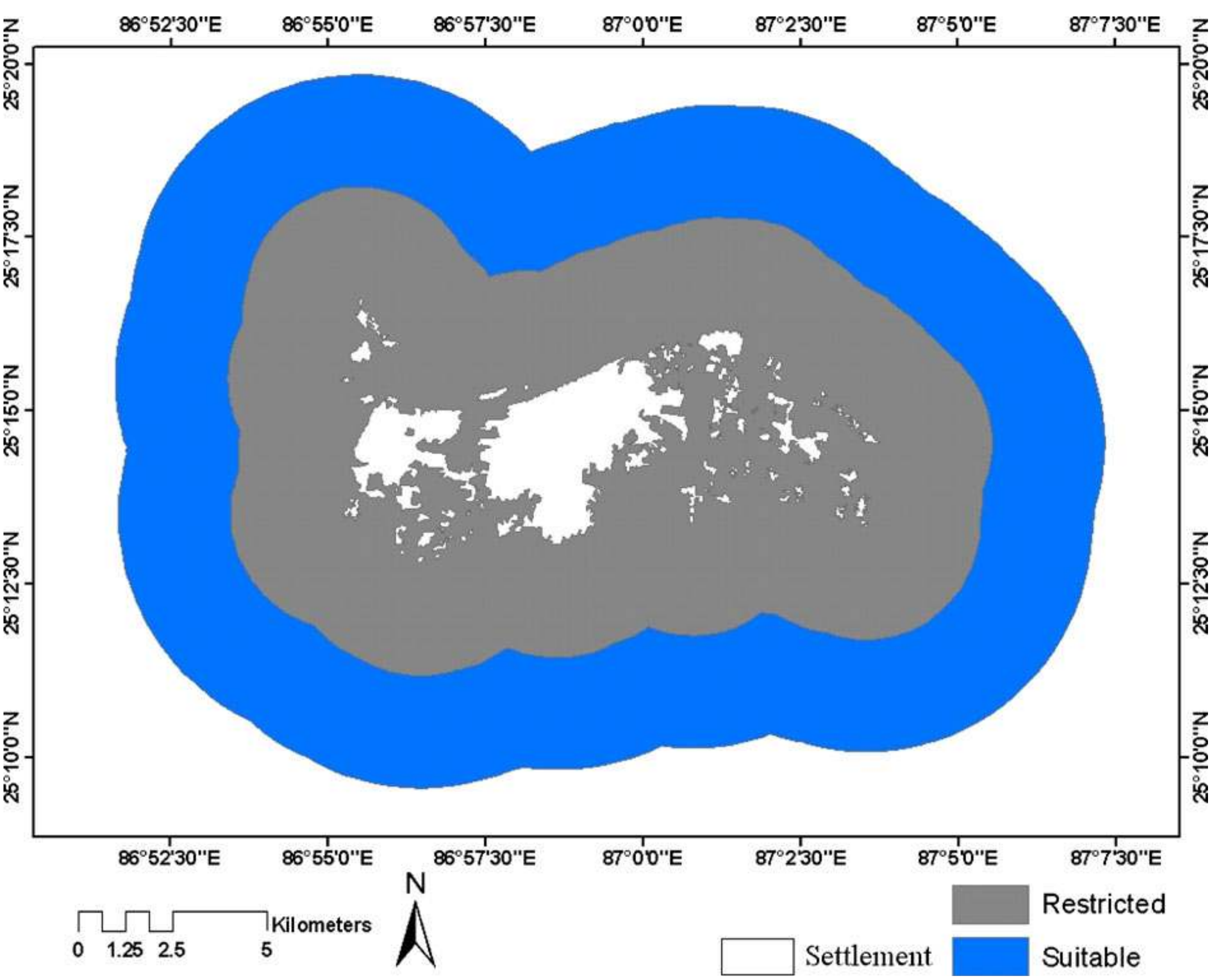

Fig. 5 Buffer map of urban city Bhagalpur

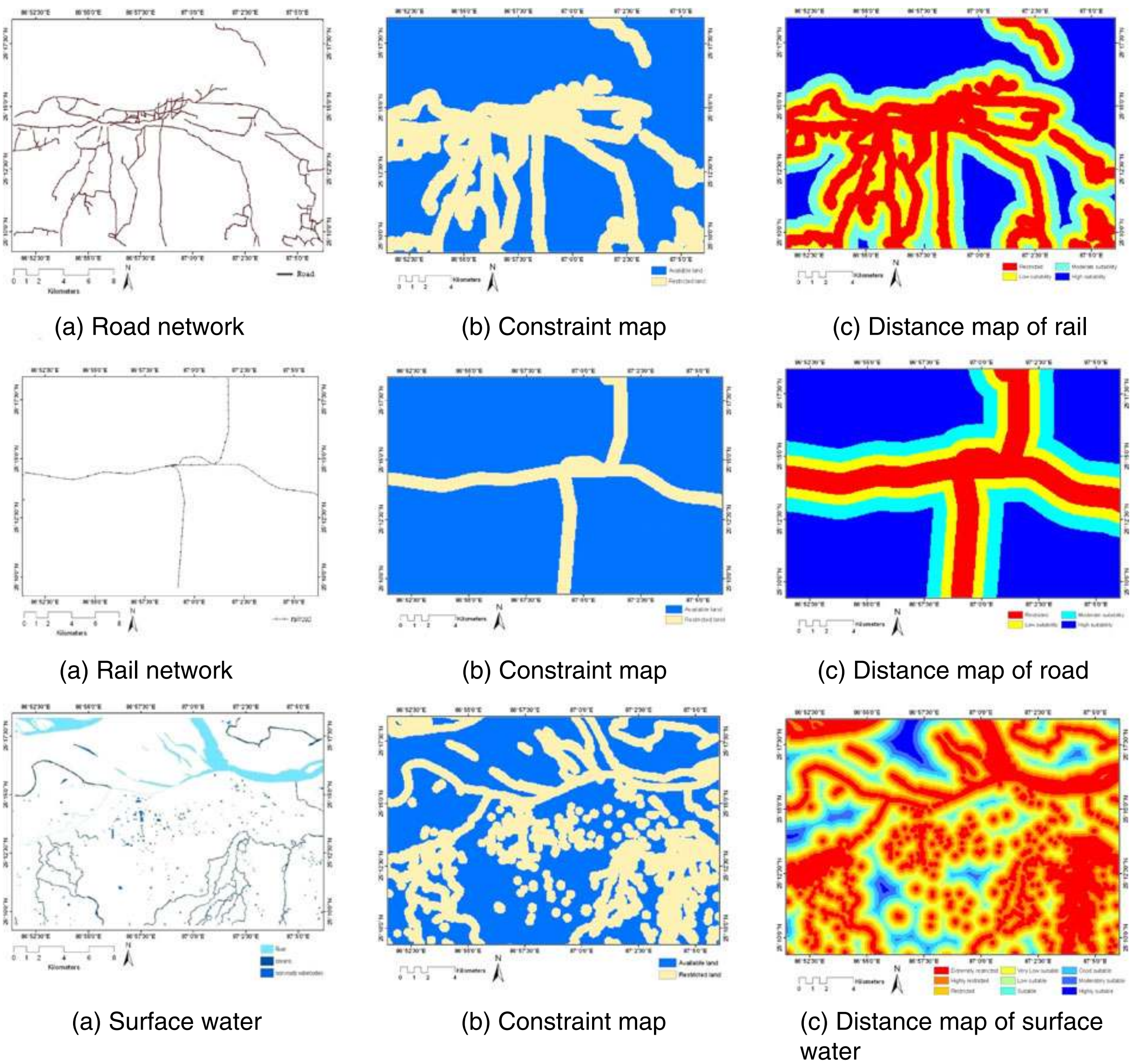

Fig. 6 Individual themes, constraint, and distance maps

not desirable region to build a disposal nearby. This was due to the possibility of contaminants from a landfill leaching to the ground water and seeping into the rivers and streams. That was also primarily due to environmental concerns, where a location farther away from a surface water source would be preferred. The final constraint map was created using overlay function with road, rail and water body constraint maps. The final constraint map gave the suitable and restricted areas for the assessment of the suitable site for disposal of municipal solid wastes.

Distance maps

Distance maps were to be made using "Spatial Analyst-Distance" option for layers associated with assumed criteria which could be ranked based on their distance from the nearest source. If so assumed, the scales were in linear relationships.

Straight line assigned values (scores) to the cells proportional to their distance from the source. The distance proximity was evaluated for road, rail and surface water. In case of surface water, it was evaluated together with river, streams as well as the waterlogged surface being considered as the unsuitable area. This gave the map of suitability range from highly restricted to highly suitable area. The distance output raster contained the measured distance from every cell to nearest source. The distance were measured and computed from cell centre to cell centre. Distance map was measured for each criteria setting equal distance. The distance analyses for road were calculated as <500, 500–1,000, 1,000–1,500, >1,500. For rail network distance defined as <500, 500–1,000, 1,000–1,500, >1,500, so for water bodies >900, 600–900, 300–600, <300. The ranking was given according to importance of the criteria as shown in Table 2. Proximity analyses for creating factor maps illustrated suitability of a specified feature that ranges from the least suitable locations to the most suitable using a range of classes.

Final factor map

The final factor map was created using an arithmetic overlay of distance maps (surface water, roads and railroads). The weighted sum overlay operation were performed giving weight scores of 0.25, for rail network, 0.25 for road networks, and 0.50 for surface water in spatial analyst corresponding to 1 as depicted in Table 2. Where, it shows the range of suitability from highly restricted to most suitable site for MSW disposal. Areas suitability for site selection was represented in gradients of color from extremely restricted to highly suitable site for landfill of municipal wastes.

Final suitability map

The final suitability map was generated by the overlay of the final constraint map and the final factor map. This approach consisted of the identification of locations that may present favorable conditions to the disposal of the wastes. The adopted criteria were applied to the spatial data using buffering capabilities within GIS and map overlays and intersection to create a composite site suitability map as shown in Fig. 7. Best suitable sites for landfill is depicted, where the classes occur as gradient of suitability from extremely restricted to highly suitable site. Restricted areas appeared in red color where landfills were ecologically and economically not viable. Different degrees of suitability were represented in different shades. The most ideal and suitable landfill site

Table 2 Distance criteria and score assignment to locate suitable site

No	Criteria	Distance map	Ranking	Gradient of suitability	Weightage overlay score
1	Distance from Road	< 500 m	1	Highly suitable	0.25
		500–1,000	2	Medium	
		1,000–1,500	3	Low suitable	
		> 1, 500	4		
2	Distance from Rail	< 500 m	1	Highly suitable	0.25
		500–1,000	2	Medium	
		1,000–1,500	3	Low suitable	
		> 1, 500	4		
3	Distance from Surface Water bodies	< 300 m	4	Restricted	0.50
		300–600	3	Low suitable	
		600–900	2	Medium	
		> 900	1	Highly suitable	
4	Slope	0–12°	1	Suitable	No score—region is totally flat Zone
4.	Distance from Settlement (Urban agglomeration)	Within municipality reach	1	Suitable	

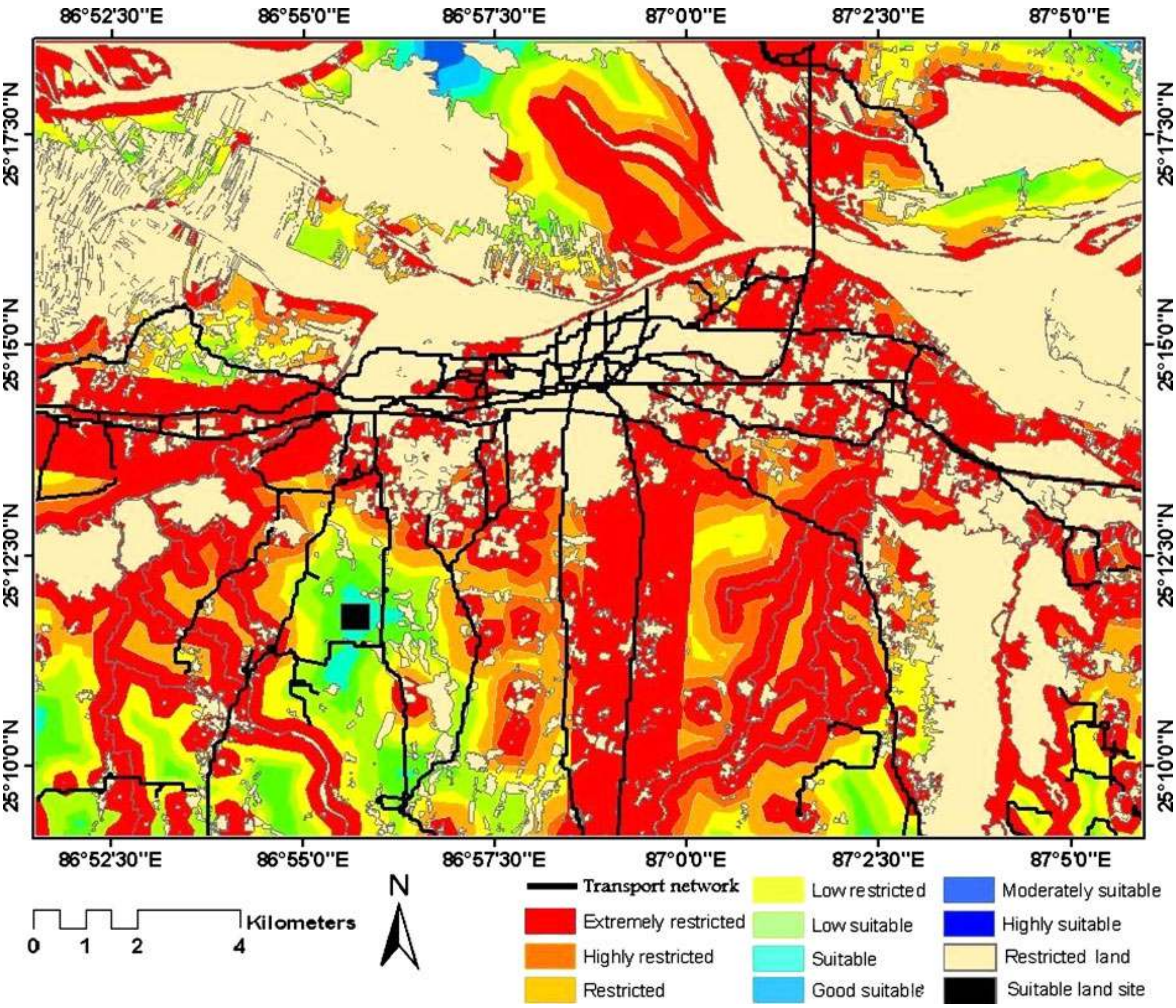

Fig. 7 Final landfill suitability map for Bhagalpur City

was marked in black which was located outskirts of the main township within municipal limits.

The highly suitable site gave the area of 1.5 km^2 which makes only 0.30% of the total area. The Bhagalpur municipal corporation needed 0.02 km^2 as it demanded from the government for the disposal of MSW. But, here it is 1.5 km^2 which is 61 times the land area demanded by the Nagar Nigam. Out of 1.5 km^2, 0.31 km^2 was suitable according to all criteria being used and taking the range of study area. Most Site Suitability Analysis for the Bhagalpur area was about 0.31 km^2 as outcome from the final result. Thus, Nagar Nigam could give a better service to the people by disposing off MSW at appropriate site. Among the suitable sites, the one selected was in the south direction. Other sites are either at the corner of the study area beyond far away from municipal limit and they were costlier for the disposal facility. This study was a contribution towards growing dense urban settlement for municipal solid waste disposal and utilization of land properly.

Conclusion

It is inferred from the study that the Geospatial approach is easily applied to other studies and easy to understand and it illustrates that areas are better or less suitable for disposal site selection. The criteria used in this study are not fixed since it can vary from place to place and these criteria can be changed accordingly. Apart from that, the present methodology can explain clearly and results in an easily understandable way. GIS indexing with constraint criteria using high resolution imagery, which helps in accurate land use land cover classification, was successfully adopted in the current study. The approach and results of the suitability map can assist in management of the solid waste by the municipal authority. The Geospatial approach definitely improves the decision making capability and understanding of solid waste management by planners in growing urban environment. Therefore, the application of Geospatial approach for disposal site selection is a cost-effective and time-saving tool compared to conventional methods in times to come.

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