Geospatial multicriteria approach for solid waste disposal site selection in Dehradun city, India

V. V. Sai Krishna[1,*], Kamal Pandey[2] and Harish Karnatak[2]

[1]Urban and Regional Studies Department, and
[2]Remote Sensing and Geoinformatics Group, Indian Institute of Remote Sensing, Dehradun 248 001, India

Solid waste generation is increasing rapidly in urban areas of India as well as globally. As land resources for waste disposal are limited in highly populated countries like India, identification of solid waste disposal sites in urban centres is a challenging task, as this involves physical, socio-economic and environmental factors. Dehradun, the capital city of Uttarakhand at present has only one disposal site which is not having good spatial accessibility for all the locations in the city and also it is an environmentally vulnerable site. The present study aims to find suitable sites for decentralized solid waste disposal using geospatial techniques with multi spatio-temporal remote sensing data. A geospatial multicriteria analysis was performed with weighted overlay technique by considering various criteria such as physical, social and demographic aspects of the city for locating the solid waste disposal site(s).

Keywords: Geospatial techniques, multi-criteria analysis, suitable site, urban solid waste.

IN today's world, rapid urbanization, industrialization, advancement of technology, sophisticated lifestyle, lack of awareness about environment vulnerabilities among the people are factors which are leading to excessive generation of solid waste[1]. Improper planning and mismanagement by civic authorities lead to nonscientific disposal of waste[2]. India, one of the most populous countries in the world, generates between 500 and 700 g of waste per head per day[3]. There is tremendous loss of natural resources in terms of environmental degradation due to direct disposal of waste[4]. Moreover, land resources for waste disposal sites are limited. Waste disposal has huge environmental impacts and can cause serious problems that include aesthetic nuisance, hazardous diseases, economic loss, water and atmospheric pollution. Presently, municipal waste is disposed unscientifically in almost every growing city in India. Over a period of time, effluent treatment plants, incineration and other techniques have been developed for treatment and disposal of industrial and hospital waste. But in urban localities, proper disposal of household garbage is emerging as a greater challenge. Collection, handling and disposal of scattered and daily generated household waste, huge in quantity require vast human and physical resources.

In developed countries, the issue of solid waste is properly handled through effective management processes such as waste reduction, reuse-recycle and scientific disposal. In most developing countries, municipal solid waste management system is either not efficient or still at the rudimentary stage and as such solid waste generated has become a threat to environment. Unplanned and non-scientific disposal mechanism of solid waste leads to degradation of natural resources creating health related problems. In developing countries there is a problem of solid waste management with no proper scientific approach[5]. The present study intends to find suitable sites for decentralized solid waste disposal generated from Dehradun City municipality and surrounding areas using remote sensing and Geographic Information System (GIS) technology. Geospatial analysis helps to prioritize dumping sites based on road network of the city.

Urban solid waste management

Remote sensing and GIS play a significant role in management of solid waste. Remote sensing helps to locate suitable sites for waste disposal using satellite imagery. The main advantage of satellite remote sensing is its repetitive and synoptic coverage which is useful for various studies in urban planning. Advancement in computer science has introduced GIS as an innovative tool in waste disposal management. GIS has emerged as a key technology to manipulate and analyse geographic data and is a powerful tool for collecting, storing, retrieving at will, displaying and transforming spatial data from the real world[6].

The location of disposal site must consider socio-economic, environmental and land use factors within the city and ensure human safety[7]. Benefits of GIS include better information management, higher quality analysis, ability to carry out 'what if?' scenario and improve project efficiency. GIS optimize the travel time and cost function while enhancing the accuracy. The role of GIS

*For correspondence. (e-mail: vsaikrishna1990@gmail.com)

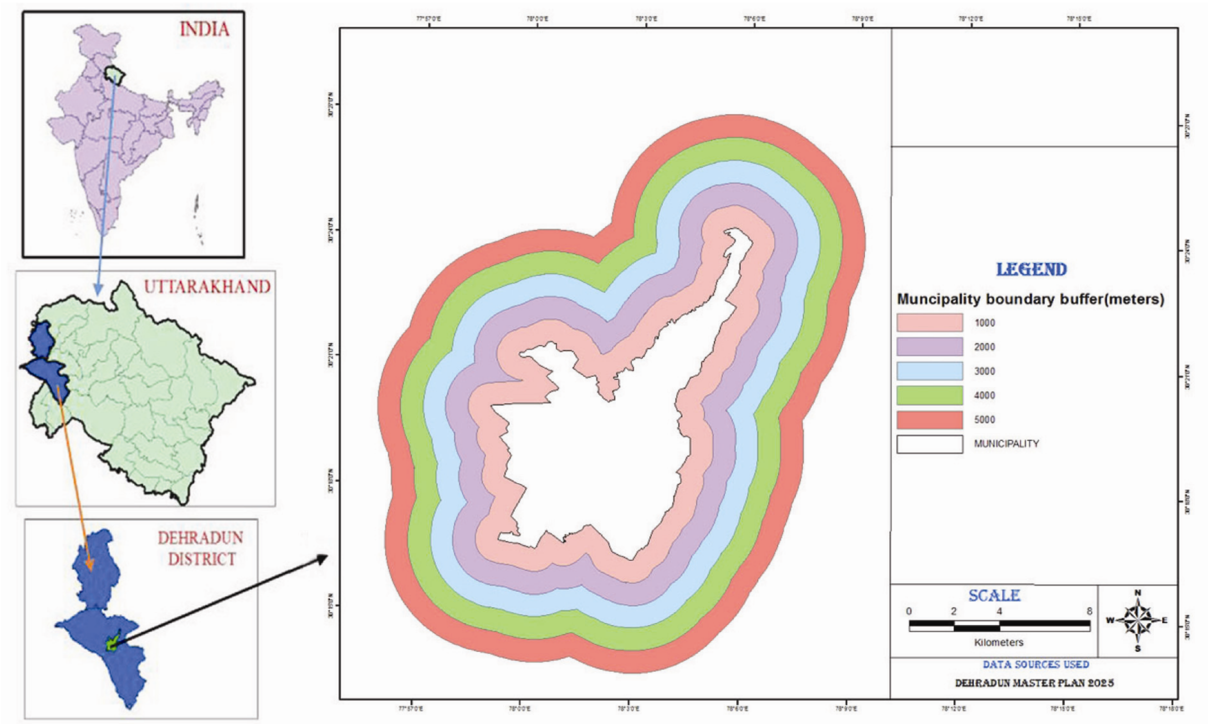

Figure 1. Study area map of Dehradun.

in solid waste management is important as many aspects of its planning and operations highly depend on spatial data. The ultimate aim of GIS is to support spatial decision making in two or three-dimensional environment[8]. In general, GIS plays a key role in maintaining an account of the data to facilitate collection operations, customer service, analysing optimal locations for transfer stations, planning routes for vehicles transporting waste from residential, commercial and industrial customers to transfer stations and from transfer stations to landfill sites, locating new landfill sites and monitoring of the landfill sites[9]. Geospatial technologies assist in identification of potential sites for disposal of solid waste[10] as well as landfill sites[11]. Analytical hierarchical process (AHP) based multi criteria decision making technique is widely used in the process of identifying suitable site for the disposal of solid waste[12]. The same geospatial approach can also be used for locating the incineration plant for municipal solid waste[13].

GIS is a tool which not only reduces time and cost of the site selection, but also provides a digital data bank for future monitoring programme of the site. It has the capability to handle and simulate necessary data gathered from various sources. It combines spatial data (maps, aerial photographs and satellite images) with quantitative, qualitative and descriptive information databases, which can support a wide range of spatial queries such as showing the least cost path or the shortest path to the disposal site[14]. All these factors have made GIS an essential tool for location studies, especially for disposal sitting using multicriteria decision analysis[15]. The availability and accuracy of data can significantly affect the results of any analysis.

Solid waste management system

Dehradun is the administrative centre and interim capital city of Uttarakhand state in the northern part of India. It lies between 29°58′N–31°2′30″N and 77°34′45″E–78°18′30″E. The total area of the city is about 300 sq. km. It is a tourist hub attracting massive floating population into the city that generates huge solid waste. Hence a 5 km buffer region to the city shown in Figure 1 was taken as the study area for the present study. The total area including the buffer zone is about 700 sq. km.

Existing solid waste management system

Dehradun Municipality has not met the conditions prescribed by the Solid Waste Management Rules 2015 (ref. 16). It lacks an environmentally sound waste disposal site. The waste collection system is inefficient with uncontrolled dumping of waste at the disposal site. Presently, Dehradun has only one disposal site (Figure 2) located on Sahastradhara road chosen unscientifically near a natural drainage network which may cause serious groundwater contamination. Unscientifically or non-technologically identified sites within the vicinity of a riverbed may get flooded during heavy rainfall that may

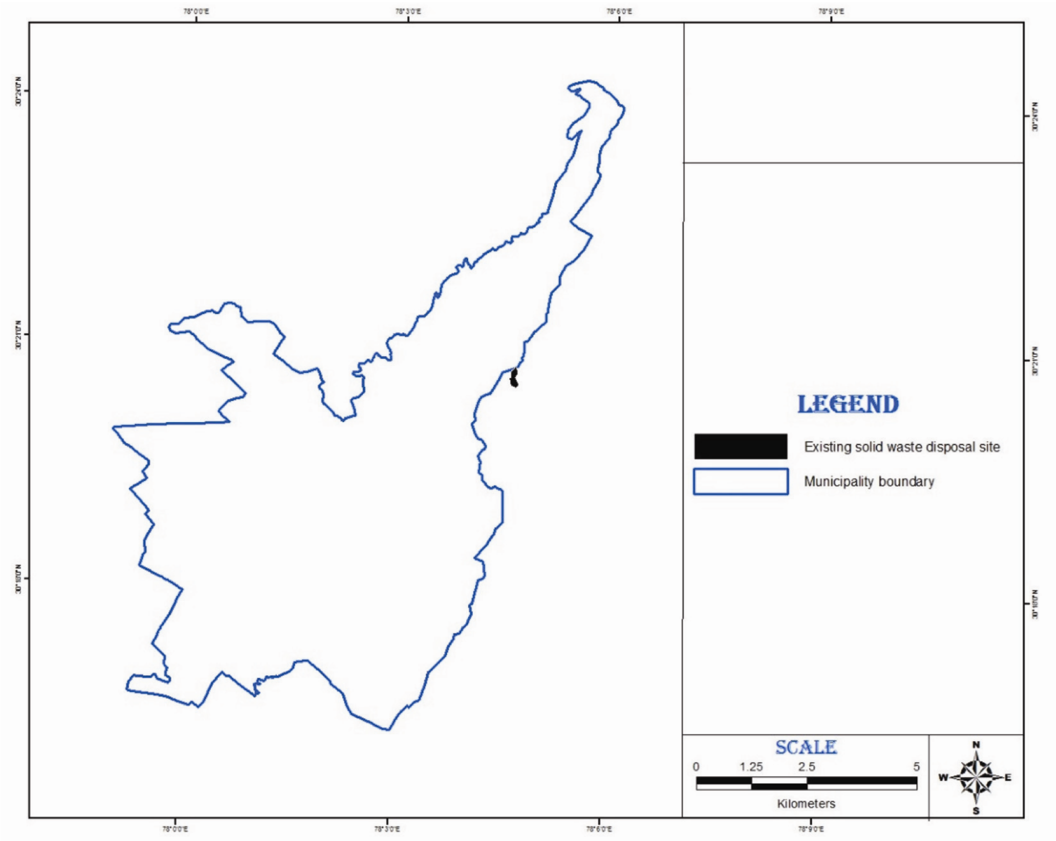

Figure 2. Location of existing solid waste disposal site in Dehradun.

Table 1. Remote sensing data used

Satellite	Sensor	Date of acquisition	Spatial resolution	Spectral resolution
Cartosat-1	Panchromatic	28 March 2010	2.5	1 band
IRS-P6	LISS-IV	28 March 2010		
		7 March 2013	5.6	3 bands

result in disturbance to hydrological cycle, economic and social losses. It has become a common practice that workers engaged in solid waste collection dump the garbage along riverbeds or on road sides, which creates severe health hazards to the city residents. Therefore the city requires immediate and sustainable measures for solid waste management. In this context an attempt has been made to identify suitable sites for solid waste disposal by using geospatial technologies.

Data and tools used

To evolve an efficient solid waste management system for Dehradun city, both primary and secondary data were collected. For further understanding the system spatially, remote sensing data was used. The primary data includes visual interpretation of satellite images, DGPS surveys and secondary data including data collected from various organizations like census, Nagar Nigam, Survey of India (SOI), Geological Survey of India, and National Bureau of Soil Survey and Land Use Planning (NBSS&LUP). The toposheets of 1 : 50,000 and 1 : 20,000 scales were used. Remote sensing data was obtained from the National Remote Sensing Centre (NRSC), Hyderabad, Bhuvan geoportal as shown in Table 1.

Methodology

The methodology adopted in this study was divided into three phases, i.e. data collection and preparation phase; design phase and choice phase. In the first phase, a detailed DGPS survey was done to collect ground control points (GCP) required for geo-referencing the satellite images as well as secondary maps such as city development plan (CDP) and master plan images. For a better satellite image interpretation, image enhancement

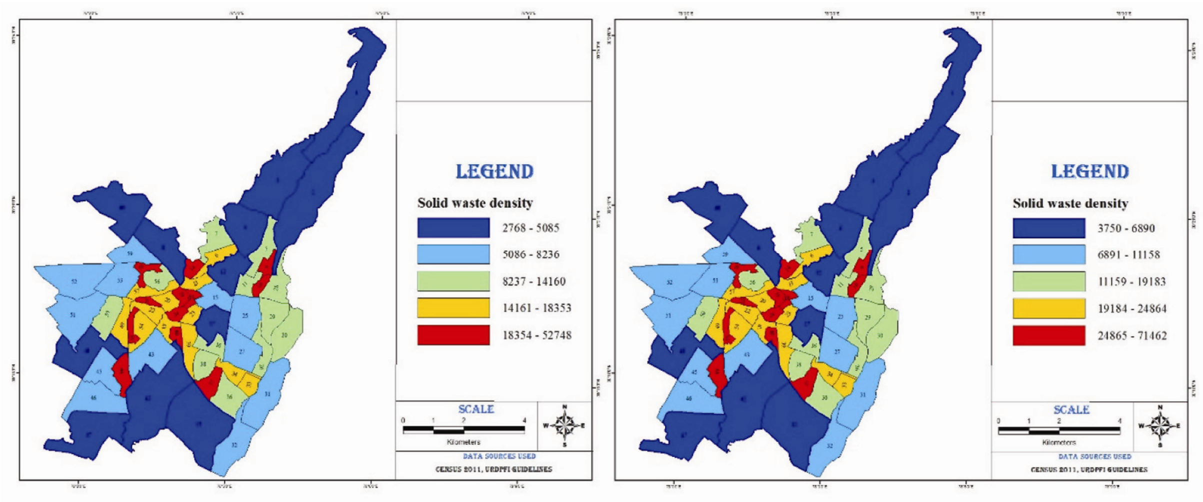

Figure 3. Ward-wise estimation of solid waste generation map in 2011 (left) and 2021 (right).

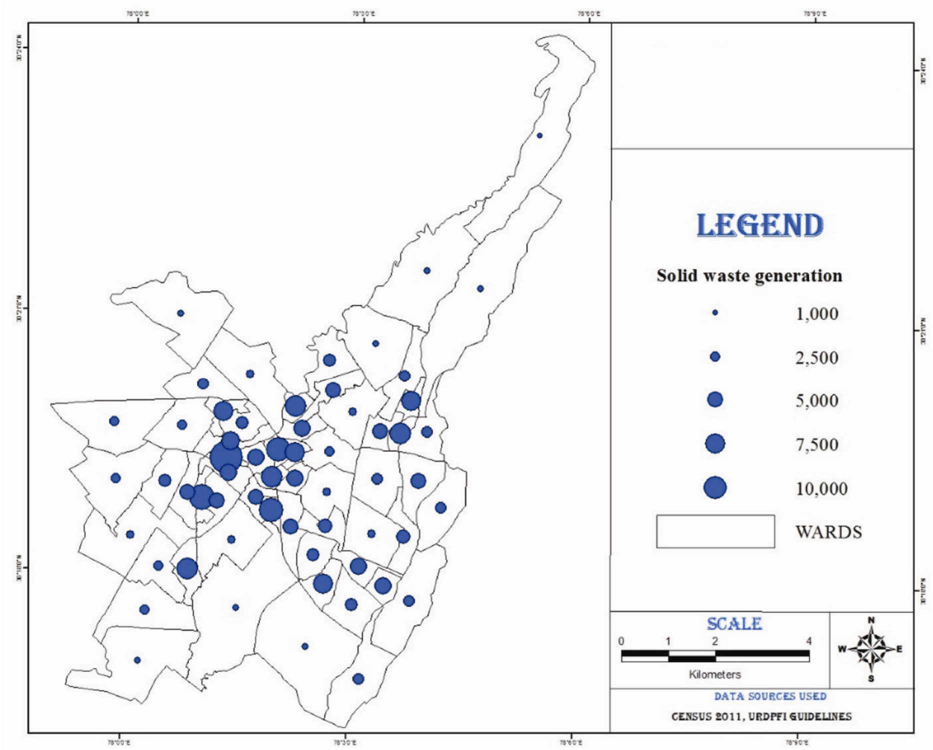

Figure 4. Ward-wise increase in solid waste generation map from 2011 to 2021.

techniques were employed. Spectral resolution of the Cartosat image was enhanced by resolution merge pan sharpening technique with LISS IV image. The merged image was then used for visual interpretation and deriving various layers/criteria used in the analysis of suitable site allocation. Image interpretation elements such as shape, size, tone, texture, pattern and various associated features were used during interpretation. In the design phase, an integrated geospatial solid waste database was created to store both spatial and non-spatial data that helps in performing concrete analysis. The importance of this data is that it can host the information derived from various data sources. Weightages were given to various criteria by taking expert opinion. In the choice phase, multicriteria decision making analysis was performed for identification and prioritization of suitable solid waste disposal sites which are briefly explained in the succeeding paragraph.

Dehradun city, on an average, generates 200 MT of solid waste per day. Ward wise solid waste generation

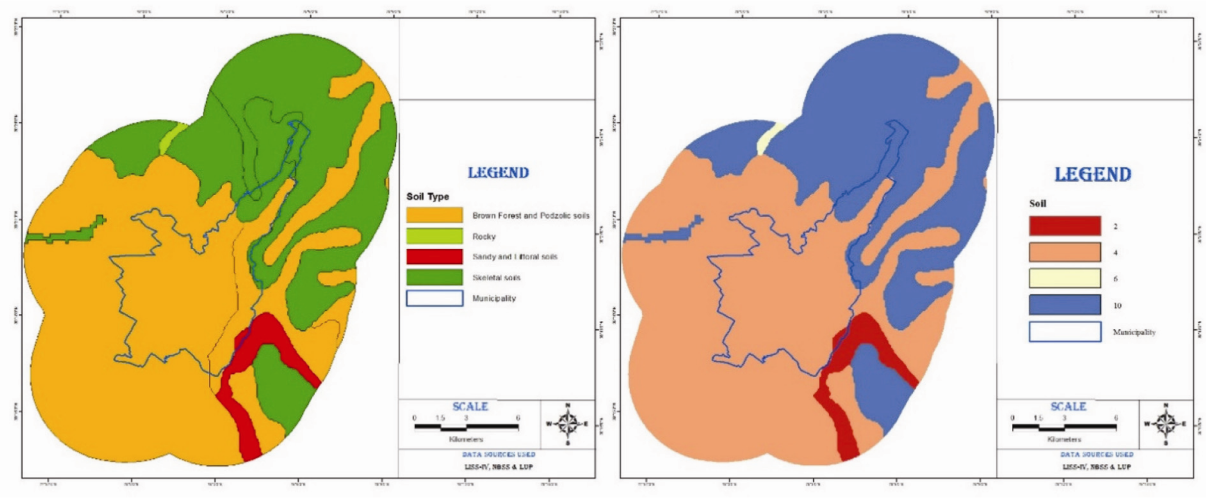

Figure 5. Soil map of the study area.

Table 2. Suitability scores given for the main criteria

Category	Main criteria	Suitability scores
Geographical and land use	Soil	25
	Slope	20
	Geomorphology	15
	Lithology	15
	Land use/land cover	10
Infrastructure	Population	10
Water resources	Drainage	5

was estimated for 2011 and 2021 as per guidelines given by Urban and Regional Development Plans Formulation and Implementation.

The total estimated solid waste generated in the city in 2011 and 2021 is 484.141 and 655.898 MT/day respectively. Per-capita solid waste generation is calculated by taking the mean of waste generation from residential, commercial, institutional and street refuse which comes to a total of 0.85 kg/person/day. Even though solid waste generation increased from 2011 to 2021 the spatial distribution of increase in pressure of handling the solid waste was not the same. Figures 3 and 4 show the ward level solid waste generation and increase in solid waste generation maps.

Analysis of site

Selecting a suitable site for solid waste disposal depends on various criteria. Therefore an integrated approach was adopted by considering seven criteria[16] which were grouped under three categories to determine the suitability (Table 2). The categories were based on their characteristics for ease of analysis. Soil, slope, geomorphology, lithology, and land use–land cover come under geographical and land use category, drainage comes under water resource category, and population comes under infrastructure category. Criteria under each category have sub-criteria. To perform the integrated weighted overlay analysis, the main criteria were assigned with suitability scores/weightages. The percentage of influence of each criteria was based on the importance of that criteria in determining the suitable site.

All these datasets were generated by performing geoprocessing tasks such as buffer, reclassify, union and clip, to ensure that all the layers are of the same geographical extent and each cell in the thematic layers is associated with one value.

Soil is the first point of contact for solid waste. Clayey soil allows least seepage making it most suitable for the disposal site allocation. Lesser the porosity and effective permeability of the soil texture, lesser is the seepage and accordingly the weightages were assigned to the different soil classes after creating a linkage between soil type and soil texture. The soil map shown in Figure 5 was prepared using IRS-P6 LISS-III sensor data with base information taken from NBSS&LUP maps. There are four sub-criteria of soils shown in Table 3 and the suitability scores are given on 2 to 10 scale for each sub-criteria.

Slope of the terrain plays an important role in solid waste disposal site identification as it has a direct impact on the run-off. As slope increases the runoff volume increases, so that there is a high probability that solid waste present at higher slopes can be washed down along with runoff which can create problems to human lives at lower slopes and on adjacent plains. Slope map shown in Figure 6 was prepared from digital elevation model (DEM) generated from Cartosat-1 stereo pair satellite data. Five sub-criteria have been identified based on slope criteria and the suitability scores on 2 to 10 scale are given in Table 4.

Geomorphology plays an important role in any kind of land use planning. Geomorphology classes are directly

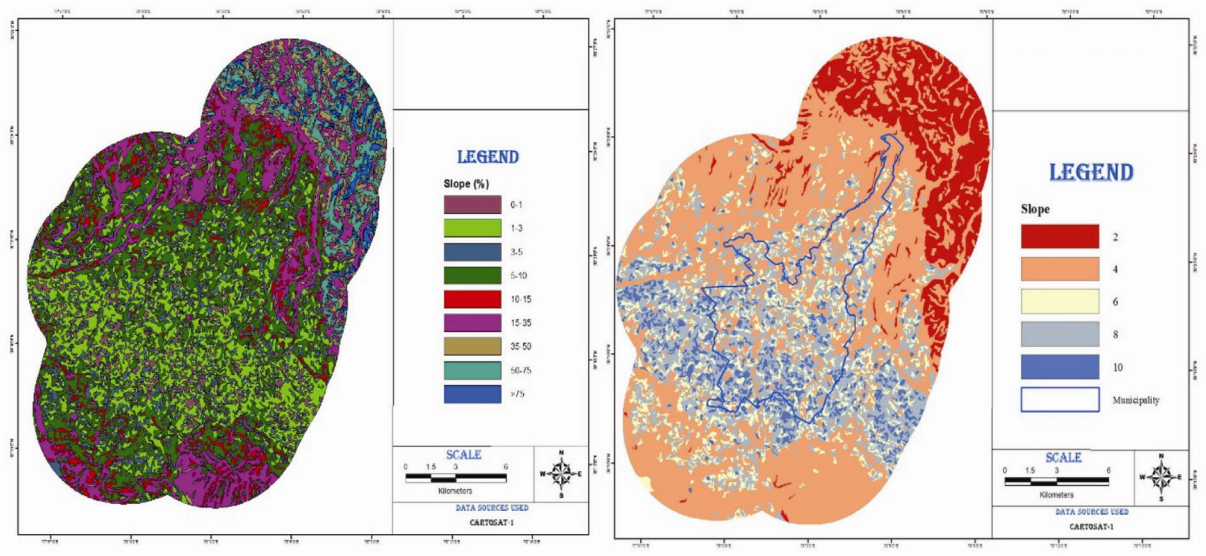

Figure 6. Slope map of the study area.

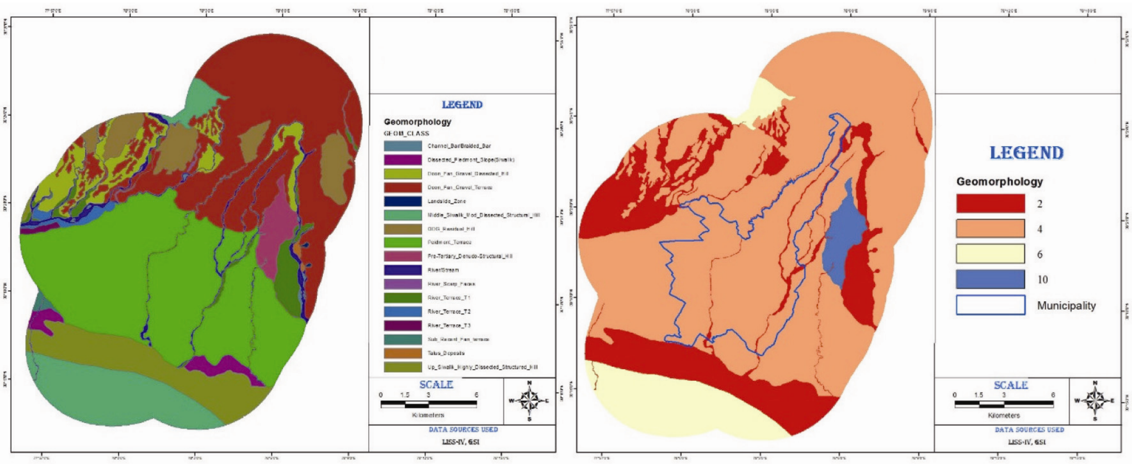

Figure 7. Geomorphology map of the study area.

Table 3. Suitability scores given for soils sub-criteria

Soil type	Suitability score
Sandy and littoral soils	2
Podzolic soils	4
Rock outcrop	6
Skeletal soils	10

Table 4. Suitability scores given for slope sub-criteria

Slope (%)	Suitability score
0–3	10
3–5	8
5–10	6
10–15	4
>15	2

linked with the ground water table. Geomorphology map shown in Figure 7 was prepared from LISS-IV and geological survey maps. There are four sub-criteria based on geomorphology criteria and suitability scores for each sub-criteria are given on 2 to 10 scale as shown in Table 5. The pre-tertiary denudational hills are considered most suitable for dumping solid waste, because they are characterized by least percolation rate.

Lithological map (Figure 8) was prepared from LISS-IV and geological survey of India maps. There are five sub-criteria based on lithology criteria and the suitability scores for each sub-criteria are shown in Table 6. Different lithology sub-criteria offer varying protection to the underground water table. The pre-tertiary rocks allow least seepage into the underground water table whereas channel bar, river/stream, river scarp faces, river terraces, landslide zones, and talus deposits permit greater contamination of groundwater.

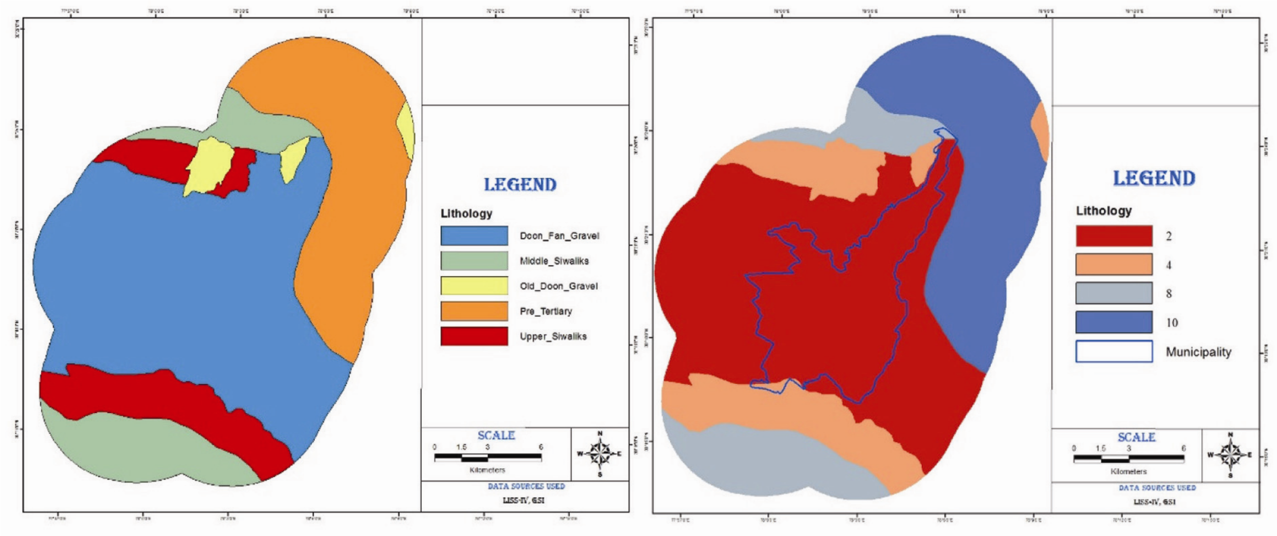

Figure 8. Lithology map of the study area.

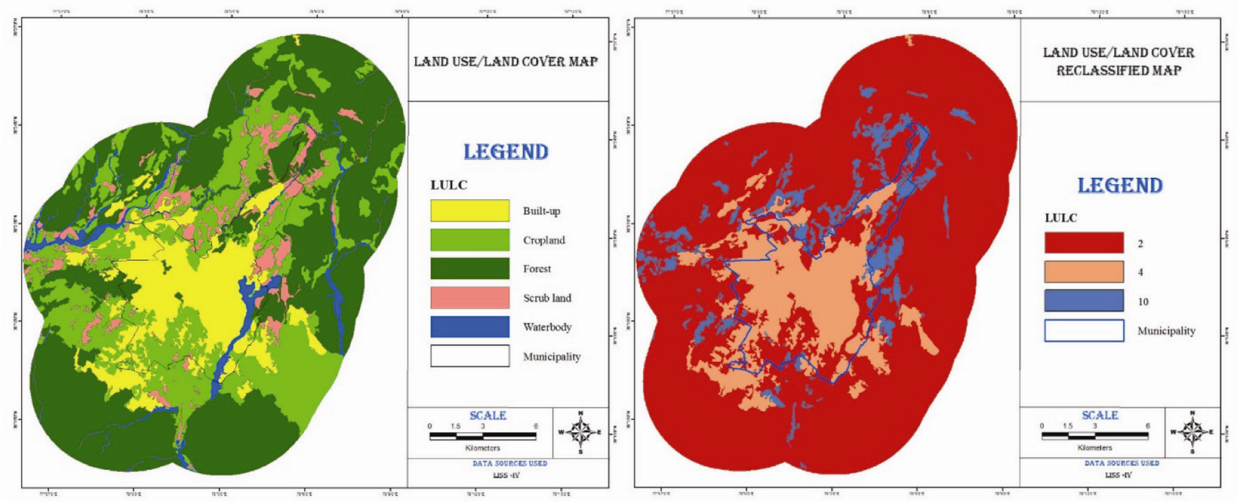

Figure 9. LU/LC map of the study area.

Table 5. Suitability scores given for geomorphology sub-criteria

Geomorphology	Suitability score
Channel bar, river/stream, river scarp faces, river terraces, landslide zone, talus deposit, up Siwalik highly dissected structural hill, Doon fan gravel dissected hill	2
Sub recent fan terrace, Doon fan gravel terrace, piedmont terrace	4
Middle Siwalik mod dissected structural hill	6
Pre-tertiary denude structural hill	10

Assessment of land use/land cover (LULC) information plays a crucial role in the identification of solid waste disposal site. The area under forest land cannot be used for municipal waste disposal activity, as it adversely affects natural forest resources. Similarly water bodies and existing built up areas should be avoided for such activity as this activity can have a direct adverse effect on the health of the residents. Scrub lands are waste lands which can serve as suitable lands for solid waste disposal. LULC map shown in Figure 9 was prepared by supervised classification of LISS-IV and Cartosat merged images. There are five sub-criteria based on this criteria

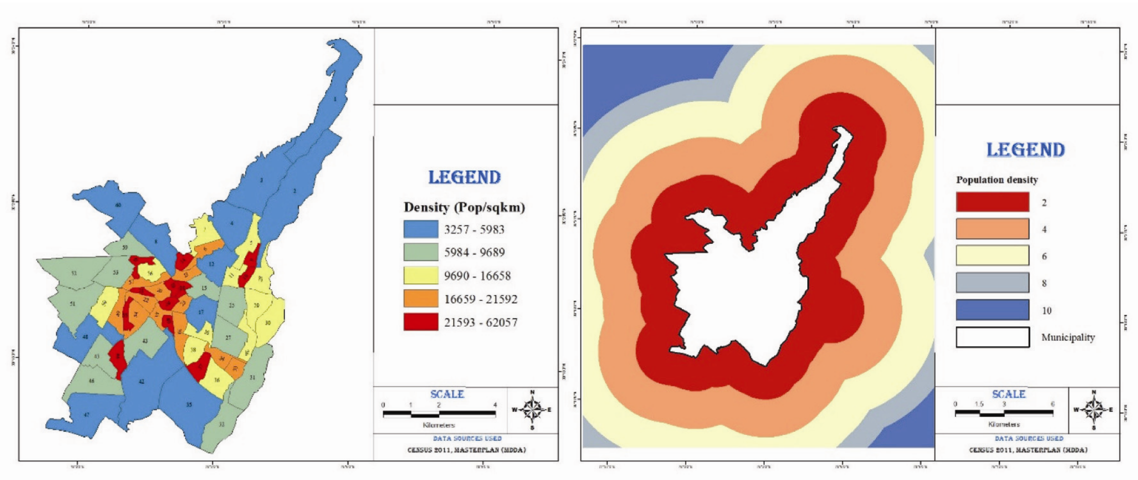

Figure 10. Population density map of the study area.

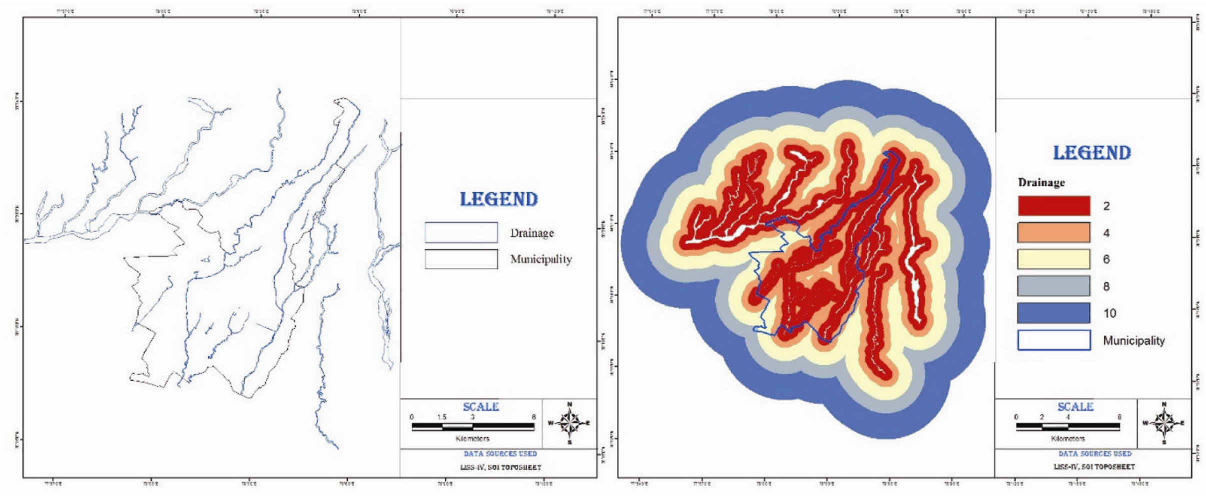

Figure 11. Drainage buffer map of the study area.

Table 6. Suitability scores given for lithology sub-criteria

Lithology	Suitability score
Doon fan gravel	2
Old doon gravel, upper siwaliks	4
Middle siwaliks	8
Pre-tertiary	10

Table 7. Suitability scores given for land use–land cover sub-criteria

Land use-land cover	Suitability score
Water body, cropland, forest	2
Built-up	4
Scrub land	10

and the suitability scores on 2 to 10 scale are given in Table 7. The LULC sub-criteria with high score are considered suitable for waste disposal site identification.

Human resource is a key factor for sustainable development of any city. Improper management of solid waste will have an adverse effect on population. Population distribution in Dehradun city shown in Figure 10 was prepared from census data. Quantile classification method was used for generating ward-wise population density distribution map. There were five sub-criteria based population distribution criteria and the suitability scores for each sub-criteria on 2 to 10 scale are shown in Table 8.

The natural drainage system of any place plays an important role in properly maintaining the hydrological cycle of that area. Natural drainage provides outlet for the run-off generated from a rainfall of particular intensity over a period of time. The site suitable for waste disposal must be away from drainage system. Drainage map shown in Figure 11 was prepared from LISS-IV and toposheet maps. A multiple ring buffer was created to cover the whole study area. There were five sub-criteria and the suitability scores shown in Table 9 were given on 2 to 10 scale for each sub-criteria.

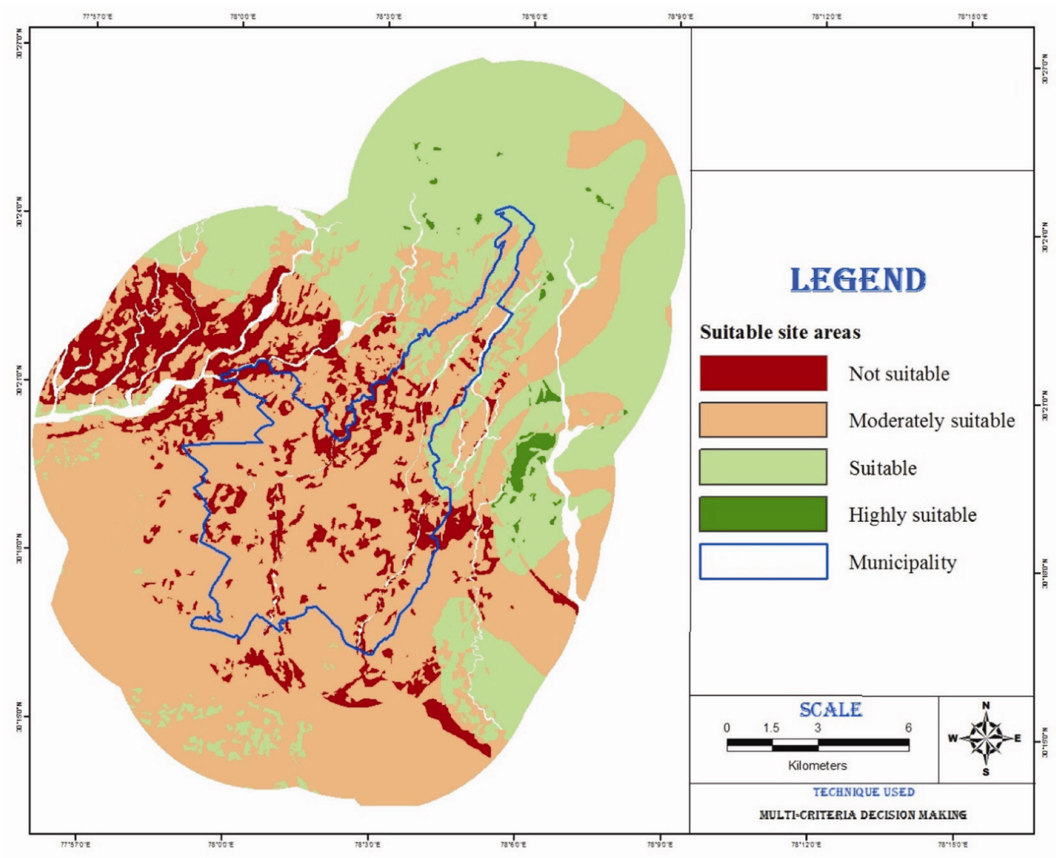

Figure 12. Suitable sites for solid waste disposal.

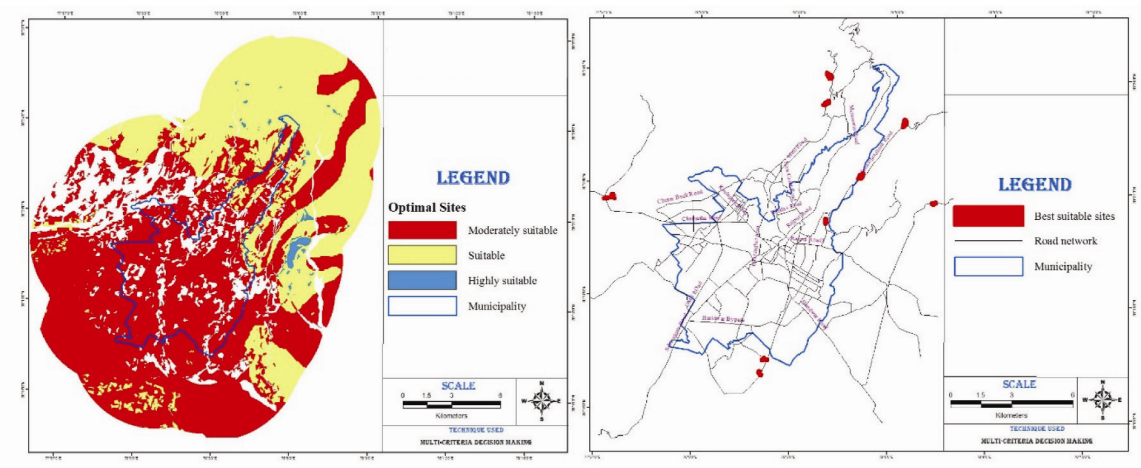

Figure 13. Optimal suitable and best suitable sites for solid waste disposal.

Multi-criteria analysis for suitable site location

A site suitability model was prepared using model builder in ArcGIS platform. The model was built in such a way that all the derived outputs must be of the same spatial extent as the area of interest. The raster operations perform better than vector operations in suitable site analysis. Therefore all thematic layers were generated in raster format. Also, all the derived outputs were brought to a common measurement scale with high scores for more suitable areas and vice versa. Weighted overlay technique[17] overlays several thematic rasters with the same measurement scale and weights according to their percentage influence. This technique was used here to get a final map identifying the site for solid waste disposal. All the water bodies were masked during the analysis. The

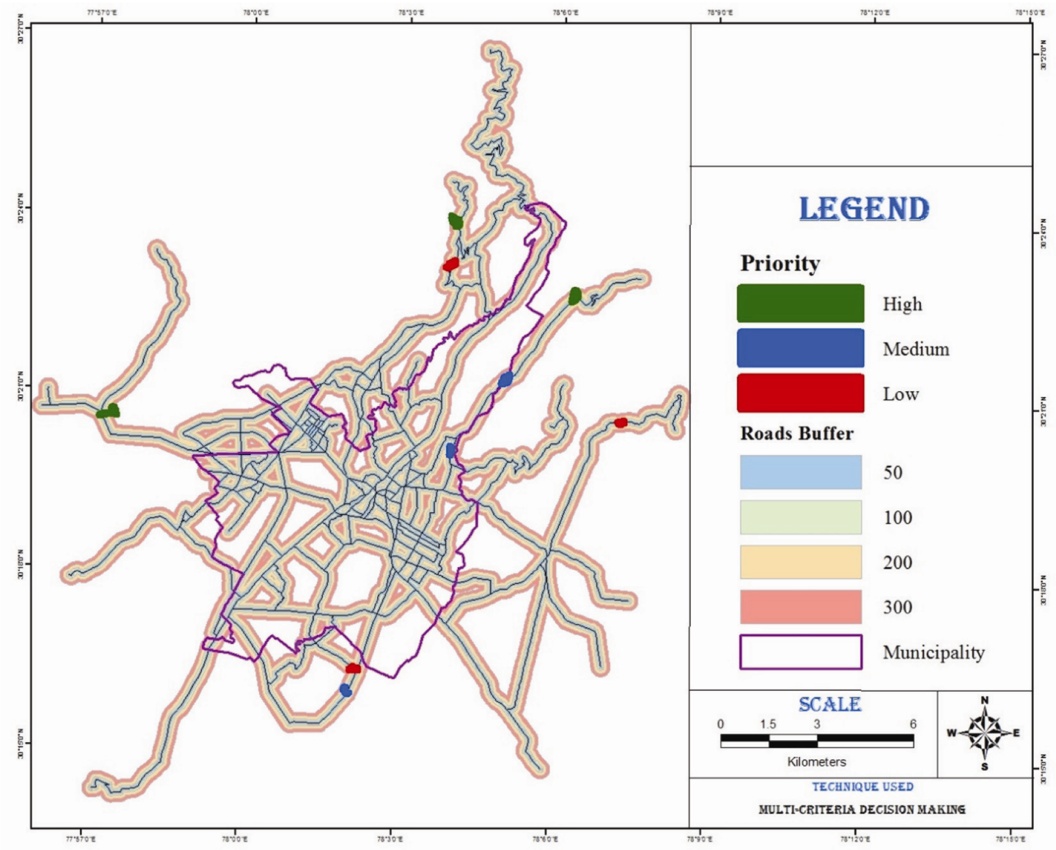

Figure 14. Prioritizing best suitable sites for solid waste disposal.

Table 8. Suitability scores given for population sub-criteria

Population density	Suitability score
3–6	10
7–10	8
11–17	6
18–22	4
23–62	2

Table 9. Suitability scores given for drainage buffer sub-criteria

Distance from drainage (m)	Suitability score
500 away	2
1000 away	4
2000 away	6
3000 away	8
5000 away	10

Table 10. Developing SQL expressions for prioritizing best sites

Priority	Buffer distance (m)	Area (sq. m)	Class
Low	50	>40,000	Suitable
Medium	50–200	<45,000	Suitable
High	100–400	> 45,000	Highly suitable

suitability map was classified into four classes namely not suitable, moderately suitable, suitable and highly suitable. The results of GIS analysis (Figure 12) show that 391.254 sq. km area is not suitable, 203.29 sq. km is moderately suitable, 115.702 sq km is suitable and 2.257 sq. km is highly suitable for disposal site.

Results and discussion

From multi-criteria decision making analysis suitable areas for solid waste disposal were identified, but these areas need to be further classified to a few better places by applying conditional parameters and spatial filters. Therefore a conditional tool was applied on the resultant map by giving a conditional value in the expression parameter which helps in removing non-suitable areas. The optimum suitable sites were obtained by applying majority filter on conditional output that helps in replacing cells based on a majority of neighbouring cells. During filtering half replacement threshold and a kernel that uses eight neighbouring cells were used. Optimal sites were vectorized to perform a vector analysis that leads to identification of best suitable sites (Figure 13). Major road network of the city was created to analyse the optimal sites. With the help of location tool, all the vector optimal sites that were intersecting within 10 m road buffer zone were identified, then from this selection a sub-selection was made using select by attribute tool. In select by attribute tool, SQL expression was applied to identify the sites which were in suitable, highly suitable classes with geographical area greater than 15,000 sq. m. Finally nine best sites were identified (Figure 14). They were prioritized by developing three rule sets (Table 10).

Conclusion

Geospatial technologies like GIS, remote sensing and DGPS survey play a prominent role in the selection of solid waste disposal sites in the proximity of a city. Also high resolution satellite remote sensing data help in making wise decisions during complex situations like site suitability analysis. GIS is helpful in identifying suitable sites that have no or minimum adverse impact on environment by considering various geospatial themes. Though GIS-based methodology is sophisticated, its success depends on the accuracy of input data. Thus with the use of advanced technologies, municipal solid waste management can be handled by city administrators more efficiently. The methodology adopted in this study for Dehradun will be helpful for policy makers and city planners for effective preparation of solid waste management guidelines.

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