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# LANDFILL SITE SELECTION THROUGH GIS APPROACH FOR FAST GROWING URBAN AREA

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**ABSTRACT**

*Landfill site selection in an urban area is a critical issue in the urban planning process because of enormous impact on the economy, ecology, and the environmental health of the region with the growth of the urbanization, larger amount of wastes that are produced and unfortunately the problem gets bigger every day. A selection of proper waste disposal site is a function of many parameters which can be involved under the Environment, Planning & Social Functions. In this paper, planning parameters are used to rank the four sites which are already proposed in the master plan of Surat. Also, the study includes proposing of new sites apart from the four proposed sites fulfilling MoEF guidelines. The whole study is carried out using GIS and AHP as a tool. The integration of both GIS and Multi-Criteria Decision Analysis (MCDA) techniques improves decision-making because it enhances an environment for transformation and combination of geographical data and stakeholders' preferences. In site selection problems, GIS perform deterministic Overlay and buffer operations while; MCDM methods evaluate alternatives based on the decision maker's subjective values and priorities*

**Key words:** Ranking; Landfill sites; GIS; AHP; Planning parameters; MoEF; CPCB; Buffering; Spatial Analysis Tool

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## 1. INTRODUCTION

Municipal solid waste (MSW) refers to the material discarded for which municipalities are usually held responsible for collection, transportation and final disposal. Due to rapid urbanization and uncontrolled growth rate of population, SWM has become acute in India.

Site selection in the aim of rubbish burying is one of the most important decisions for urban planner and municipalities' office especially in India where there are some important economic, social, environmental and infrastructure challenges to be considered for site selection regarding to the sustainable development strategy.

A proper site must fulfil all the aspects of sustainable development in order to be acceptable for all professionals who are working in the field of land management as well as must pay attention the distance as a considerable point. From a scientific point of view, site selection using geographic information systems can be a perfect solution while it has a comprehensive way which pays attention all restrictions simultaneously.

In spite of the increasing stress towards the waste reduction at the source, as well as recovery and recycling of the solid waste, disposal of solid waste by land filling remain the most commonly employed method. Landfill incorporates an engineered method of disposal of solid waste on land in a manner that minimizes environmental hazards by spreading the solid waste in thin layers, compacting the solid waste to the smallest practical volume and applying a cover at the end of the operating day. However, with the increased population density and urban infrastructure, several key considerations are required to be taken into account to ensure its overall sustainability, especially those associated with its economics, optimized siting and operation. The development of a municipal solid waste landfill requires the acquisition of large tracts of land and its suitable siting in a pre-existing urban matrix comprised of diverse competing land uses.

A landfill site has to meet several locational and geotechnical design criterion and be acceptable to the public. The criteria involved in landfill site selection include environmental, economic and socio-political criteria, some of which may be in conflict. MoEF (Ministry of Environment & Forestry) and CPCB (Central Pollution Control Board, India) through NEERI (National Environmental Engineering Research Institute) have developed guidelines for site selection for solid waste disposal in India.

The present study focuses on an optimized land use site selection based on multi-criteria decision analysis and geographic information system based (GIS) overlay analysis.

The most appropriate landfill site has been identified for Surat(Gujarat), a typical urbanizing city of India. Several important factors and criteria were considered to arrive at the optimum siting decision including the pre-existing land use, location of barren sites, water bodies, vicinity to airport, population density and site topography. Thematic maps of the selected criteria were developed within the paradigm of standard GIS software. Subsequently, weightings were assigned to each criterion depending upon their relative importance, and ratings in accordance with the relative magnitude of impact. A GIS-based overlay analysis was performed to identify the optimum site for the landfill, one which fulfilled all of the desired attributes.

## 2. STUDY AREA BACKGROUND

### 2.1. Study Area Profile

Surat(Gujarat, India) is located in coastal region of western India. The City is located at 21.17°N 72.83°E. Surat is the 4th fastest growing city of India and it is business capital of State Gujarat. Total city area is 326.56 Square Kilometer. The City has main potential in forms of river Tapi. The City has CBD (Old City) and Non-CBD (New City) areas. The city is administrated by local government called Surat Municipal Corporation (SMC). The development, town planning schemes are prepare by SUDA i.e. Surat Urban Development

Authority. The City is well connected with others in form of Roads, Railway and Air transportation. Surat is second largest city in Gujarat and ninth largest in India.

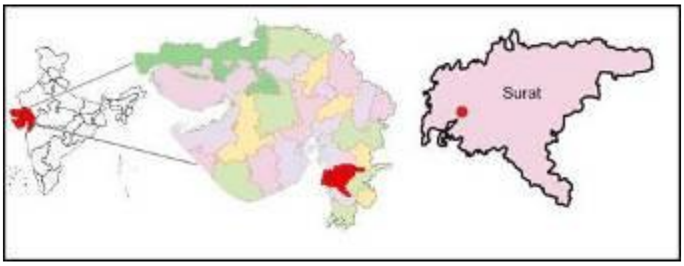


**Figure 1** Location of study area Surat

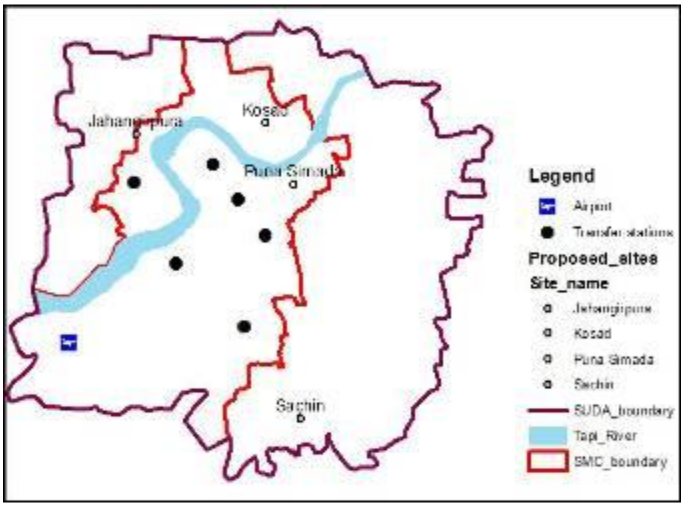


**Figure 2** Locations of various features of Surat

## 2.2. Present Scenario of Solid Waste Disposal in Surat

Surat generates 400gms per capita per day of waste amounting to roughly 1000 metric tons. This is collected by SMC, private contractors and the rag pickers. About 70 percent of the waste generated every day is contributed by households, shops and other commercial establishments. Just over 30 percent of the total waste generated is recyclable. This comprises of paper, plastic, metal, brick stone and glass primarily. Combustible waste accounts for 22.75 percent of the total and organic waste is nearly 42 percent.

Processing and disposal methods like incineration etc. are not used in Surat. Land available for treatment and disposal of waste, where the land filling is carried out, is about 10 km from the city. The life expectancy of land for the treatment and disposal of waste is 30 years at the Khajod final disposal site. There is sanitary landfill cell created and the cell is ready for its use for disposal of inert material obtained at the end of treatment process of MSW Treatment.

Before MSW-2000 rules; MSW were dumped to open space in Bhatar. After MSW -2000 rules, Surat Municipal Corporation has developed. Sanitary Landfill site in the area about 200 hectors at Khajod. An area of 1.25 lac cu.m is under operation for receiving inert residues and sanitary landfill site with 6.25 lac cu.m capacity is ready for utilization.

## 3. SITING METHODOLOGY

Landfill site selection is a complicated multi criteria land use planning that should convince all related stakeholders with different insights. The approach for landfill siting is based on conflicting opinions among planning expertise. In order to gain optimized siting decision, the issue was investigated in different viewpoints. The first step was based on opinion sampling and questionnaire results of 15 experts familiar with local situations, the national planning legislations and international practices. Fifteen planning constraints or parameters were built in hierarchical structure. Using these opinions of all the experts, the result was analysed in SPSS software to check the validity of the parameters and less important parameters were discarded and at the end nine planning parameters were considered for the study.

**Table 1** Planning parameters used and its descriptions

| Sr.No | Planning Parameters | Description |
|---|---|---|
| 1 | Zoning Density | Zoning Regulation may impact the development of landfill |
| 2 | Distance from transfer stations | Lesser the distance, less time and energy consumed in transporting the waste to landfill |
| 3 | Site Topography | Slope should be such that it does not encourage leaching. |
| 4 | Residential landuse | Land use specifications should allow the development of landfill |
| 5 | Size | It should be comparable with the amount of waste and size of the city |
| 6 | Access to roads | It allows smooth functioning of transferring waste to the landfill sites. |
| 7 | Distance from river | It keeps checks for water body pollution especially when it is a source of drinking water. |
| 8 | Distance from airport | To avoid the possibility of bird-hit with aircraft in vicinity of landfill site. |
| 9. | Future expansion | Important as in future the waste generation quantities and the population both will increase |

In the next step, data were collected regarding all nine parameters and GIS-database in form of base maps were developed in ArcGIS 10.0.0. In the third stage, the criteria standardization and criteria weighting were accomplished using AHP (Analytical Hierarchical Process) which was also based on experts’ opinion. The relative importance weights of the parameters were estimated, respectively, using Analytical Hierarchy process and rank ordering methods based on different experts’ opinions.

Thereafter, by using pairwise comparison method, the suitability maps for landfill siting in Surat, India, was evaluated as per planning visions. In the fourth stage, the final suitability map was obtained after crossing three resulted maps in different visions and reported in five suitability classes for landfill construction.

In the last stage, a comprehensive field visit was performed to verify the selected site obtained from the proposed model. This field inspection has confirmed the proposed integrating approach for the landfill siting.

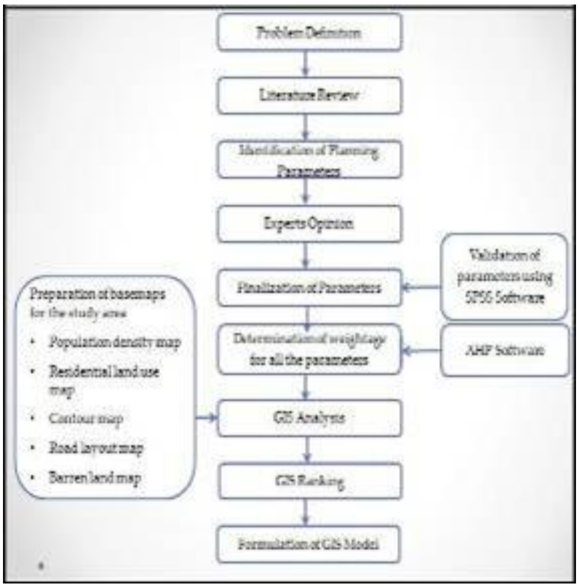


**Figure 3** Methodology

This research work starts with identifying the problem related to the selection of landfill site. The objectives and scope of study are clearly identified. This will be followed by gathering and understanding of urban planning parameters and GIS fundamentals from the various different literature.

On the basis of the literature, urban planning parameters are identified which are important for Indian conditions. To validate these planning parameters, experts' opinions are required to be collected to carry further pilot and final survey for SPSS analysis. The analysis of the data will provide required information about the various landfill site options. Weightages are derived for all the planning parameters using pair-wise comparison method (AHP).

**Table 3** MoEF (Ministry of Environment & Forestry) and CPCB (Central Pollution Control Board) criteria for sitting of landfill sites in India

| Sr. No. | Features | Minimum Sitting distance |
|---|---|---|
| 1. | Habitation | 500 m |
| 2. | Rivers, lakes , water bodies | 200 m |
| 3. | Non meandering water | 30 m |
| 4. | Highway, railways and roadways | 300 m from center line |
| 5. | Costal regulation zoning | Sanitary landfill site not permitted |
| 6. | Earthquake Zone | 500 m from fault line fracture |
| 7. | Flood prone area(100 years flood plains) | Sanitary landfill site not permitted |
| 8. | Water Table | Over 2 m below bottom of landfill base liner |
| 9. | Airport | 20 km |
| 10. | Population within 500 m radius | 0-100 PPHA (Person Per Hectare) |
| 11. | Distance from transfer stations | 10-20 km |

All the required information about the study area are collected and basemaps are prepared in ArcGIS 10. Landuse map is generated in ERDAS IMAGINE. Ranking and suitability model are prepared in ArcGIS 10. With the help of GIS modelling, the best suitable site for landfill will be selected and their preferences for future use will be decided.

# 4. DATA COLLECTION AND ANALYSIS

## 4.1. Analytical Hierarchical Process (AHP)

MCE is a device which enables people to make the most appropriate choice among many criteria, and it is a widely used concept. AHP is one such multi-criteria decision-making method. The AHP is used as a decision analysis device is a mathematical method developed by Saaty in 1977 for analyzing complex decisions involving many criteria. It is widely used by decision-makers and researchers as an MCE device. Pairwise comparison, which is applied within the scope of the AHP technique, provides a comparison of criteria which are used in decision analysis and determines values for each of these criteria.

**Table 4** The AHP matrix generated by pairwise comparison

| | P.D | D.T.S | S.T | L | S | A.R | F.E | D.R | D.A |
|---|---|---|---|---|---|---|---|---|---|
| **P.D** | 1 | 1.91 | 1.99 | 0.86 | 2.3 | 1.7 | 1.2 | 1.6 | 1.0 |
| **D.T.S** | 0.52 | 1 | 2.76 | 1.18 | 2.9 | 0.8 | 1.7 | 1.6 | 1.3 |
| **S.T** | 0.50 | 0.36 | 1 | 0.81 | 2.0 | 1.6 | 0.9 | 1.4 | 1.3 |
| **L** | 1.16 | 0.84 | 1.22 | 1 | 4.1 | 1.9 | 2.3 | 1.8 | 1.7 |
| **S** | 0.43 | 0.33 | 0.47 | 0.24 | 1 | 0.5 | 1.0 | 1.7 | 1.1 |
| **A.R** | 0.57 | 1.16 | 0.58 | 0.50 | 1.6 | 1 | 2.8 | 1.2 | 2.2 |
| **F.E** | 0.77 | 0.55 | 1.05 | 0.43 | 0.9 | 0.3 | 1 | 1.2 | 1.1 |
| **D.R** | 0.59 | 0.59 | 0.67 | 0.55 | 0.5 | 0.8 | 0. | 1 | 0.3 |
| **D.A** | 0.93 | 0.75 | 0.73 | 0.57 | 0.8 | 0.4 | 0.8 | 2.5 | 1 |

P.D = Population Density A.R = Access to Roads

D.T.S = Distance from Transfer Station

F. E = Future Expansion S.T = Site Topography

D.R = Distance from River L = Landuse

D.A = Distance from Airport S = Size

In AHP, a matrix is generated as a result of pairwise comparisons and criteria weights are reached as a result of these calculations. Also, it is possible to determine the consistency ratio (CR) of decisions in pairwise comparison. CR reveals the random probability of values being obtained in a pairwise comparison matrix.

**Table 5** Weights calculated through AHP

| Parameters | Weights |
|---|---|
| Population Density | 0.1538 |
| Distance from Transfer Station | 0.1465 |
| Site Topography | 0.1064 |
| Landuse | 0.1655 |
| Size | 0.0685 |
| Access to Roads | 0.1210 |
| Future Expansion | 0.0800 |
| Distance from River | 0.0676 |
| Distance from Airport | 0.0907 |

Consistency Index – 0.0719 < 0.1…… O.K

Max. Eigen Value – 9.5756

## 4.2. Thematic Map Preparation

The primary data sources for the study included the toposheets of Surat of the scale 1:50,000, which were used to prepare the base map for the study. Water bodies, road network, Digital Elevation Model (DTM), existing landuse pattern, permanent and temporary rivers, availability of barren land and vicinity of airport were all prepared based on the Survey of India map and google earth maps by digitization.

The land use map was generated through the image interpretation and classification of the Indian Remote Sensing satellite IRS1D imagery of Surat district of 22.8 m resolution using ERDAS IMAGINE. Subsequently, the thematic maps of habitation, sensitive sites and waste lands were derived from land use map using standard procedures. Secondary data was collected by ground truth and surveys conducted at the concerned sites. The digitization and analysis of the thematic maps were performed within the framework of the well-known desktop GIS software; ArcGIS Desktop 10.0.

Digital thematic maps were generated by employing the following procedures:

- Scanning of the available primary paper maps.
- Georeferencing the scanned map to earth coordinates.
- On screen digitizing of the primary maps, thereby generating the digital thematic maps, each characterizing the influencing factor for landfill site selection.
- Locating the GPS coordinates and entering in the database as latitude and longitude.
- Conversion of the latitude and longitude data into the point data using the software.
- Addition of the attribute data to the locations.

***Population Density***

In the SMC area, the ward of Anjana had a density of 1807 persons per hectare ; Karanj had 1113 persons per hectare while wards such as Khajod, Abhva, Vanta, Dumas, Vadod, Sarasana, Gaviyar, Variav, Sulatanabad and Jahangirpura, Budiya had densities as low as less than 10 persons per hectare as per 2011 census.

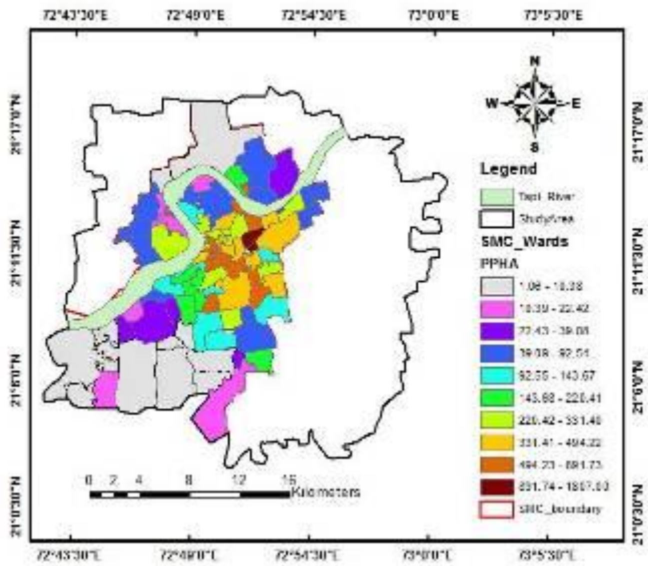


**Figure 4** Ward wise Population Density map

### *Access to Roads*

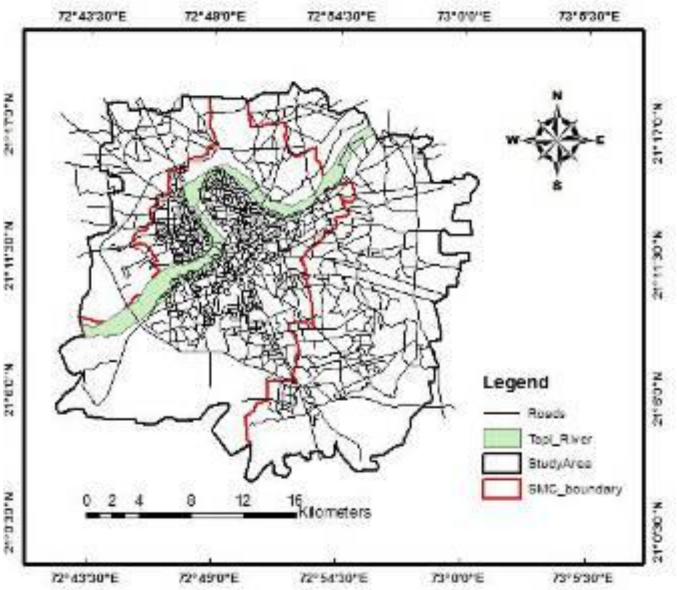


**Figure 5** Location of roads and its buffering according to MSW 2000 guidelines

Minimum distance from the network is imported in order to avoid visual impact and other nuisances. Roads plus 300 m buffer areas from both sides should be applied. The landfill site should not be placed too far away from existing road networks to avoid the expensive cost of constructing connecting roads.

### *Landuse Pattern*

In the study area, there are different land uses. Land use types were grouped and ranked according to their suitability for a landfill site as unsuitable, moderately suitable and suitable for a landfill site by assigning values 0 to 9. The land use vector map was then converted to a raster map.

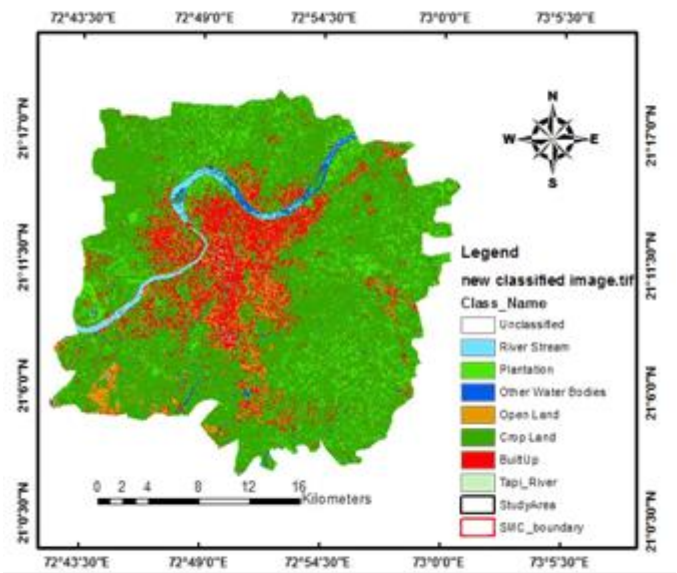


**Figure 6** Landuse Map

### *Slope*

Digital Elevation Model (DEM), also referred to as the Digital Terrain Analysis, is a digital representation of earth's topography in a continuous way. A slope map was generated from DEM. The potential for slope failure was related to the degree or grade of the topography. Slope failure underneath or adjacent to landfills, will result in waste containment failure and release of debris into the surrounding area. Land with slopes greater than 15% should be considered unsuitable for waste disposal sites. The slope layer was classified as suitable or unsuitable for a landfill site by assigning values 1 and 0, respectively.

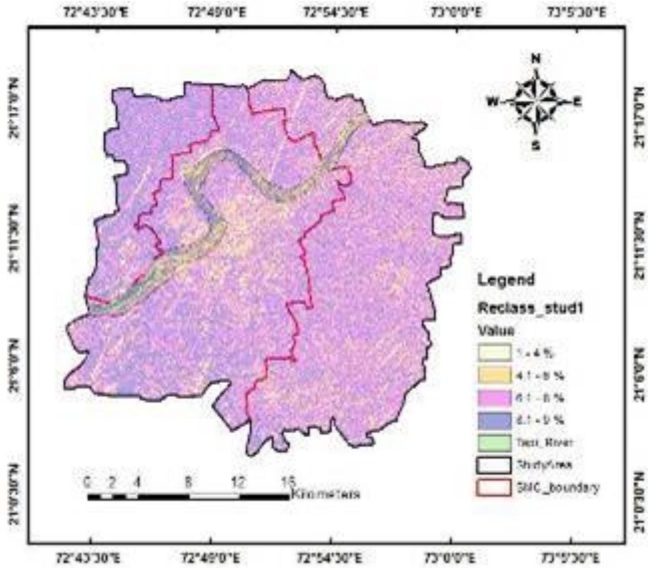


**Figure 7** DEM to Slope map

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### *Euclidean Distance from Transfer stations*

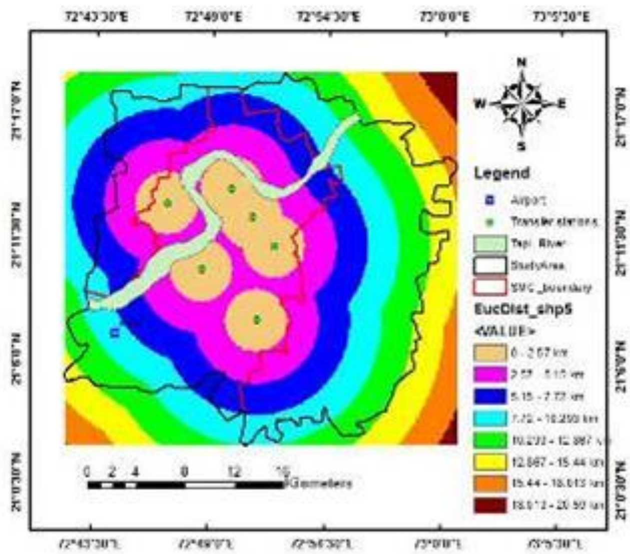


**Figure 8** Euclidean distance map of the transfer stations

**Table 6** Euclidean Distance from Transfer Stations

| Euclidean Distance (km) | New Field Value | Scale Value |
|---|---|---|
| 0-2.57 | 1 | Restricted |
| 2.57-5.15 | 2 | Restricted |
| 5.15-7.72 | 3 | 2 |
| 7.72-10.30 | 4 | 3 |
| 10.30-12.87 | 5 | 4 |
| 12.87-15.44 | 6 | 5 |
| 15.44-18.013 | 7 | 6 |
| 18.013-20.59 | 8 | 7 |
| No Data | No Data | 8 |

The Euclidean distance map of the transfer stations were reclassified and given new field values as shown in Table. This was done in order to rate areas suitable for landfill site because the further the area is from the transfer stations the less suitable it is.

## 5. DATA ANALYSIS AND RESULTS

GIS data sets of the study area (e.g., land use, roads, airport, transfer stations, slope, population density, water bodies) were collected for the study area from different sources and subsequently digitized. Elevation maps were prepared based on the LANSAT II Satellite image. The digitization and analysis of the maps were performed using Erdas Imagine software and ArcGIS Desktop 10. The AHP weights were calculated using online AHP software. In this study, nine criteria were selected for evaluating landfill suitability. Firstly, constraints were masked.

In this study, landfill suitability map was prepared 12 map layers including distance from residential and industrial areas, distance from rivers, lakes, wetlands, coastal area, distance from transfer stations, distance from airport, distance from built-up, land use, slope, distance from roads and railway and elevation. ArcGIS software was used this process for weighted overlay analyses. Determined numerical values from LSI divided into five grades (Strictly Restricted, Less Preferable, Good, Preferable, Most Preferable) according to guidelines and buffer zones were built. The higher the score is more suitable area for landfills.

**Table 7** Parametric data related to the sites

| Sr. No. | Parameters | Weights | Jahan gir-pura | Kosad | Puna Simada | Sachin |
|---|---|---|---|---|---|---|
| 1. | Popu. Density (PPHA) | 0.15 | 7.41 | 92.54 | 472.95 | 49.2 |
| 2. | Distance from transfer stations (km) | 0.14 | 14.3 | 12.73 | 11.52 | 16.53 |
| 3. | Slope (%) | 0.10 | 6.2 | 4.2 | 3 | 17.3 |
| 4. | Land use | 0.16 | Crop Land | Crop Land | Crop Land | Crop Land |
| 5. | Size (Ha) | 0.06 | 147 | 186 | 209 | 169 |
| 6. | Access to roads (km) | 0.12 | 0.07 | 0.314 | 0.057 | 0.115 |
| 7. | Future expansion (km) | 0.08 | 44 | 34 | 59 | 77 |
| 8. | Dist. From river (km) | 0.06 | 0.11 | 0.2207 | 0.1025 | 1.4 |
| 9. | Dist. From airport (km) | 0.091 | 8.1 | 19.4 | 18.61 | 14.94 |

Table presents the data related to planning parameters for all the four proposed sites. The above data are normalised and are shown in table 6.2. For normalising process, all the data are divided by the highest value among each planning parameters. Therefore, the site having highest value for that parameter will be normalised to 1 and other sites will be normalised respectively. After normalising all the data, their sum is computed by multiplying weight of that parameter with the values of all the parameters for all the four sites. Using the spatial analytical tool like buffering, weighted overlay, reclassify the best sites were identified.

**Table 8** Ranking of Proposed Sites

| Sr. No | Parameters | Weights | Jahangir-pura | Kosad | Puna Simada | Sachin |
|---|---|---|---|---|---|---|
| 1. | Popu. Density | 0.15 | 1 | 0.08 | 0.16 | 0.15 |
| 2. | Distance from transfer stations | 0.14 | 0.804 | 0.905 | 1 | 0.697 |
| 3. | Slope | 0.10 | 0.484 | 0.714 | 1 | 0.173 |
| 4. | Landuse | 0.16 | 1 | 1 | 1 | 1 |
| 5. | Size | 0.06 | 0.704 | 0.806 | 1 | 0.808 |
| 6. | Access to roads | 0.12 | 0.721 | 0.181 | 1 | 0.496 |
| 7. | Future expansion | 0.08 | 0.571 | 0.441 | 0.766 | 1 |
| 8. | Dist. From river | 0.06 | 0.082 | 0.158 | 0.073 | 1 |
| 9. | Dist. From airport | 0.09 | 0.417 | 1 | 0.959 | 0.77 |
| | Ranking Sum = (Weights x Data) | | 0.71 | 0.60 | 0.79 | 0.64 |
| | Rank | | 2 | 4 | 1 | 3 |

Output values of the resultant maps were prepared using overlay analyses of ArcGIS Spatial Analyst tool. Land suitability of the study area was calculated by LSI. Calculated LSI varied between 0-9. The very high and very low suitable areas were determined. Pixels with 0 (coloured red) were considered as very low suitable and were excluded from the alternative candidates sites to be examined as disposal areas. On the other hand, pixels with values around 9 are likely to be more suitable or preferable were coloured green.

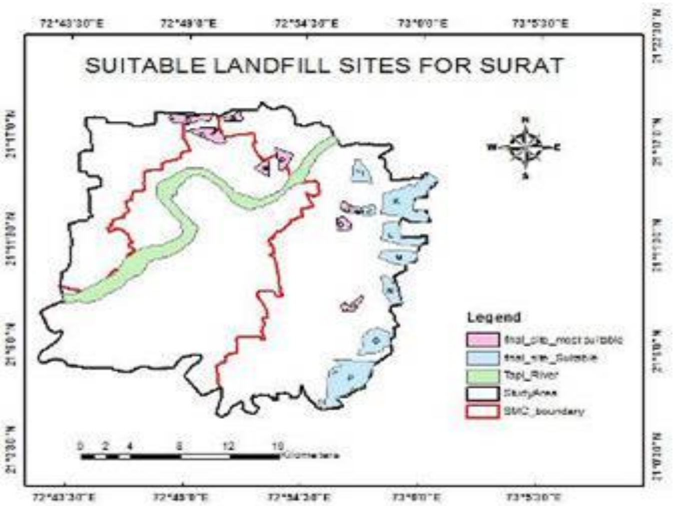


**Figure 8** Most Suitable and Suitable sites according to guidelines

In order to have a size with the full complements of facilities, areas less than 90 hectares were masked out within the most suitable and suitable class in the study area as shown in the figure using majority filter and con tool. The major locations were identified in the area under study.

**Table 9** Statistical Analysis for most Suitable Alternative Locations of Landfill Site

| Class | Site name | Area(Ha) |
|---|---|---|
| Most Suitable | A | 90.52 |
| Most Suitable | B | 228.66 |
| Most Suitable | C | 260.58 |
| Most Suitable | D | 177.52 |
| Most Suitable | E | 106.16 |
| Most Suitable | F | 112.66 |
| Most Suitable | G | 116.72 |
| Most Suitable | H | 107.73 |
| Suitable | I | 234.18 |
| Suitable | J | 95.04 |
| Suitable | K | 1051.06 |
| Suitable | L | 404.46 |
| Suitable | M | 326.45 |
| Suitable | N | 261.63 |
| Suitable | O | 453.12 |
| Suitable | P | 1114.31 |

Out of all the suitable sites particularly 5 sites are selected which are most suitable considering transportation expenditure and travel time. Sites A,B,C,D and E were found to be most suitable according to transportation expenditure and travel time. Table shows the distances from selected sites and transfer stations.

**Table 10** Distance between sites and transfer stations

Distance Matrix (Km)

| | A | B | C | D | E |
|---|---|---|---|---|---|
| **Bhatar** | 15.44 | 14.46 | 13.23 | 13.61 | 11.87 |
| **Katargam** | 8.33 | 7.98 | 6.37 | 7.16 | 5.41 |
| **Varachha** | 10.35 | 10.71 | 8.68 | 7.86 | 6.18 |
| **Anjana** | 12.78 | 13.61 | 11.69 | 9.21 | 7.98 |
| **Pal** | 11.93 | 9.68 | 9.04 | 12.38 | 10.62 |
| **Bhestan** | 18.76 | 18.94 | 17.04 | 15.30 | 14.14 |
| **Total length of trip** | 77.56 | 75.38 | 66.05 | 65.52 | 56.20 |
| **Avereage length of trip** | 20.68 | 20.10 | 17.61 | 17.47 | 14.98 |

From economy in transportation point of view, Site E located near Valak village is considered as the best suitable site among all the suitable sites.

## 6. CONCLUSIONS

GIS as a decision support tool for landfill siting has been proven to be useful in finding suitable sites for landfill siting purposes. In this study, GIS software was used to locate landfill sites by creating maps according to the set criteria. A landfill siting process requires evaluating many criteria and processing much spatial information.

The following can be concluded after the study:

- It is observed that out of all the four sites Puna Simada is the most suitable site from planning point of view. Jahangirpura site was found to be second most suitable whereas Sachin was ranked third and Kosad is least suitable.
- Among all the urban planning parameters, population density has the maximum weightage with respect to all others.
- The various sites are located in the areas like Vev, Pasodra, Khatodra, Umbhel, Haripura, Chalthan, Karan, Kachholi, Taraj, Vaktana, Kosami, Vaswari, Laskana, Timbarva.
- Sites A, B, C, D and E were found to be most suitable according to transportation expenditure and travel time.
- From economy in transportation point of view, Site E located near Valak village is considered as the best suitable site among all the suitable sites.
- During this study, the utilization of GIS as a tool in siting new landfills was employed and safe conclusions are arrived at concerning potential sites. The result of the application of GIS-based models was based on urban planning factors and constraints, potential sites were found based on these criteria.
- The site is located close enough to transport routes, which ensures that economic costs of implementation are minimal. At the end of the analysis, appropriate MSW landfill sites are identified. These sites generally satisfy the minimum requirements of the landfill sites.

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