The studies on “GIS based municipal solid waste management of Rohtak city” were carried out in the Department of Environmental Sciences, M.D.U. Rohtak during the years 2012 to 2016. The materials and methods used during the course of the study are presented here. The more specific methodology used to carry out the objectives is presented in their respective chapters for the sake of continuity and completeness of that chapter.

3.1 Materials

3.1.1 Spatial data

- Toposheet- Number H43W9 of scale 1:50,000. The Projection system was UTM and Datum was WGS84. It was purchased from Haryana Geospatial data center, Survey of India, Sector 32-A Chandigarh.

Fig.3.1 Toposheet of study area.
- **Cartosat 1 imagery** - Panchromatic imagery, spatial resolution is 2.5 m, temporal resolution, 5 Days and Radiometric resolution, 10-bit sensitivity. Date of acquisition 28 March 2013. Shown in Fig. 3.1.

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**Fig. 3.2** Cartosat 1 imagery in Arc GIS 9.3.
• **Master plan of Rohtak for the year 2031** - It was collected from the Rohtak Town Planning office.

![Fig. 3.3 Plan map of study area for year 2031.](image)

• **Block map** - It was obtained from Municipal Corporation Rohtak.

![Fig. 3.4 Block map of study area.](image)
• *Google earth image* - It was generated from mosaicking of zoomed subsets taken from Google Earth, this was necessary due to non-availability high-resolution data for road mapping and detailed study of densely populated areas. The Cartosat-1 data was not useful in high-density areas due to poor spectral resolution. Shown in Fig.3.2. is the Google earth mosaic overlapped on the Cartosat-1 imagery.

Fig. 3.5 Mosaic prepared from Google Earth overlaid on Cartosat-1 imagery in Arc GIS 9.3.

### 3.1.2 Attribute data

Following attribution data were collected from Municipal Corporation Rohtak-

- Block wise population information
- Specifications about waste bins
- Number of / and specifications about waste collection vehicles
- Details about present waste management and processing plant.

The following data was collected through survey and experimental setup.

- Ground water table
- Wind direction
- Soil permeability
- Elevation

The methodology of the above attributes is explained in the “Methods” section.
Software’s- The following software’s were used during the course of the study. For image processing: Erdas 10, Geographical Information System software: ArcMap 9.3.

Instruments- The type and description of the instruments used in the work are described below.

Anemometer- Lutron makes, AM4201 model. It was used to note the speed of the wind.

Wind vane – Self-constructed wind was used to find out the direction of wind

GPS – e-trex Garmin handheld model was used for taking the coordinate value for the sampling sites.

Bomb Calorimeter-Metrex makes, Digital model. Used for the estimation for the calorific value of the solid waste.
3.2 Methods-
The methodologies used during the course of the study are presented in the following text.

- Georeferencing was done using ERDAS software using the projection system: UTM, Standard System Model: WGS 84. Image to image as well as through keyboard.

- Data for the following criteria, Soil Permeability, ground water depth, elevation, annual distribution of wind direction frequency and speed which is to be used in the study for selection of suitable site for municipal waste dumping was not available at all or was not available on the micro scale required for the study, hence the information was gathered through field surveys, measurements, and analysis of samples in the laboratory.

- Sampling - For the collection of samples for determining the permeability of the soil, survey, and collection of data on ground water level, and elevation. The sites for the observation, measurement or sample collection was done by generating a grid over the study area by using “create fishnet tool” in ArcGIS. Each square of the grid was of 1x1 km. All measurements, observations, and samples were taken as far as possible from the centroid of each grid.
Soil permeability - Sampling for the analysis of soil samples was done by taking three soil samples from each grid and mixing the three samples to form a composite sample which was taken as a representative sample of the grid. Soil sampling was done only for areas outside the municipal boundary. Soil samples were taken from a depth of 30 cm.

Ground water depth for determining the groundwater level survey of three pumps in each grid was done. The owner of tube wells was questioned regarding the depth of the ground water.

### 3.2.1 Digitization of Thematic Layers

The various maps available were used to create thematic maps or layers of the themes to be used in the GIS software for achieving the objectives of the study. These layers were generated by using block map of Rohtak city (Fig. 3.4), Toposheet (Fig.3.1) and city plan map (Fig.3.3) obtained from MCR, Survey of India and Town planning office.

1. **Demarcation of blocks**- Rohtak city divided into 488 blocks as shown in Fig.3.7.
Fig. 3.7 Block demarcation map.
2. **Waste management zone** - Municipal Corporation Rohtak divided the city into 6 zones for waste collection, as shown in Fig.3.8.

![Fig.3.8 Municipal solid waste collection, zone map.](image-url)
3. Wards-

Demarcation of wards-The ward map was digitized using the block map of Rohtak city. There are 20 wards in Rohtak city.

Fig. 3.9 Ward demarcation map.
4. **Railway track, Drain, and canal** - These were digitized from the Toposheet and depicted in Fig. 3.10.

![Fig. 3.10 Map representing railway track, JLN Canal, and Drain No.8.](image1)

5. **Road network** - It was digitized from Cartosat-1 imagery and mosaicked Google image. The digitized map is shown in Fig. 3.11.

![Fig. 3.11 Map showing road network of Rohtak city.](image2)
6. **Land use and land cover**- This layer was digitized from the interpretation of Cartosat-1 and mosaicked Google image. Along with ground-truthing survey. The LULC map of Rohtak area is shown in Fig.3.12.

![Image showing Land use and Land cover map of Rohtak city.](image)

**Fig. 3.12 Map showing the Land use and Land cover map of Rohtak city.**

The area covered by Municipal corporation boundary is 139.4 square kilometer. Further division of land use area is given in Table 3.1

<table>
<thead>
<tr>
<th>Type</th>
<th>Area (km²)</th>
<th>Percentage of area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial</td>
<td>8.00</td>
<td>5.7</td>
</tr>
<tr>
<td>Agriculture</td>
<td>67.00</td>
<td>48.1</td>
</tr>
<tr>
<td>Commercial</td>
<td>0.40</td>
<td>0.3</td>
</tr>
<tr>
<td>Public utility</td>
<td>13.00</td>
<td>9.3</td>
</tr>
<tr>
<td>Residential</td>
<td>20.00</td>
<td>14.3</td>
</tr>
<tr>
<td>Unbuilt residential</td>
<td>16.00</td>
<td>11.5</td>
</tr>
<tr>
<td>Water body</td>
<td>2.00</td>
<td>1.4</td>
</tr>
<tr>
<td>Transport and water system</td>
<td>13.00</td>
<td>9.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>139.4</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>
Description of land use-

*Industrial* - All small and medium industries.

*Agriculture* - Cultivated land, waterlogged land, Poultry farms, degraded land, scrub land.

*Commercial* - Retail trade, wholesale trade, warehousing and storage, restaurant, hotels, cinema and other places etc.

*Public utility* - Disposal works/solid waste disposal, public and semi-public use (mini secretariat, judicial complex, jail/ police station and other institutions, educational, medical), open space (Sports ground, parks, other recreational use, cemeteries, crematoria etc).

*Residential* - Sectors, colonies (only built up area).

*Unbuilt residential* - Vacant plots of sectors and colonies.

*Water bodies* - Ponds and water tanks.

*Transport and water system* - Railway and siding, road and siding, bus stand and parking, canal, drain.
7. Surface water bodies were digitized from image interpretation of Cartosat-1 and mosaicked Google imagery. The surface water bodies are represented by village ponds, water work storage tanks and lakes. The map of the surface water bodies is given in Fig.3.13.

![Fig.3.13 Map represents the spatial distribution of surface water body of the study area.](image1)

8. Dumpsite locations of the old abandoned and functional dump sites are presented in Fig.3.14. Digitization was done from the mosaicked Google Earth image.

![Fig.3.14 Map representing the location of old and present dumpsite at study area.](image2)
9. **Sensitive area** – In this layer, two sites are presented as a sensitive area. Lake Tilyar and Archaeological area. Archaeological reserved area which includes peer colony, Khokhara Khot, Fateh puri and Bhom Nagar. Shown in Fig. 3.15.

![Fig.3.15 Map showing the sensitive area of the study area.](image)

11. **Wind direction**- It was measured using a self-constructed wind vane. The dial of the wind vane was oriented north using a magnetic compass as a reference. Measurements were taken for 15 minutes at 8 am, 2 pm and 8 pm on each day of the month for one year. The height of measurements was 10 m above the ground. Wind observations were collected- N, NE, E, ES, S, SW, W, and WN directions.

12. **Wind speed**- It was measured using anemometer (Luttron AM-4201). Measurements were made on the Km/h scale. The measured values were grouped into 3 intervals 1-5 Km/h, 5.1-15 Km/h and >15 Km/h. Less than 1Km/h was taken as calm.

13. **Windrose**- This shows the frequency of wind direction and percentage of wind speeds in each direction. Windrose was constructed from the wind direction and wind speed data given in Table 10 and Table 11 (Annexure I)
respectively. A wind rose was developed to know the average wind speed and direction of wind blowing over a one year period in the study area. Diagrammatically it is shown in Fig.3.16. In Fig three colors were used to show the wind speed, among which green color -1-5 Km/h, Yellow- 5.1-15 Km/h, and Red- >15 Km/h.

![Windrose showing Direction and speed of the wind.](image)

**14. Elevation**- GPS reading for the measurement of elevation was done in each grid of fishnet, as far as possible at the Centroid of the grid (representative area).

### 3.2.2 Mosaic Preparation

The mosaic was prepared by using subsets from Google Earth. The Google Earth image of the area of interest (Central part of the city which has congested housing and streets) was zoomed to a suitable useful level and subsets were saved as JPEG images. Four Ground Control Points (GCP) per subset were taken. The GCPs were used for the Georeferencing of each subset. After Georeferencing all subsets were mosaicked in ERDAS 9.0 software. This created a high-resolution image. It was prepared due to its high spatial and spectral resolution required for the research work. The conceptual flow chart is shown in Fig. 3.17.
3.2.3 Area and length estimation of various features-

The Projected coordinate system (PCS) of data source was WGS 1984 UTM ZONE 43N. The area of interest includes municipal corporation limits, wards, blocks, residential, unbuilt residential, industrial, commercial, public utility, water bodies, agriculture, solid waste collection zones and road length.
3.2.4 Estimation of per capita waste generation and waste characteristics

A sample survey of the city was conducted for determining the per capita income and composition of the waste. The composition and quantity of municipal waste generated will help in deciding the management plan for designing the operations for the efficient management of municipal solid.

The investigation was carried out repeatedly in the city of Rohtak, for one month. Waste samples were collected from three levels of waste disposal, waste from housing units, waste from community bins and waste from the dumpsite. Fig.3.19 presents the procedure adopted for sampling and analysis of municipal solid waste.
Colonies were classified into two categories class A (low economy) and Class B (high economy) on the basis of their economic status (Fig.3.20). Economic status of the colony was differentiated on the basis of the size of the plots, colony infrastructure, building structure and the type and a number of vehicles. Ten representative colonies each, from both the classes, were selected and ten housing units from each colony class were selected for the first level sampling. The community bins serving respective colony were used for waste sampling at the second level. The waste samples collected from the housing units in each colony were mixed to make a composite sample of each colony; the weight of these composite samples was taken. At second level, samples from community bins in each colony were mixed colony-wise to obtain composite samples of community bin of the respective colony. For third level sampling, ten samples collected from dumpsite were mixed to form a composite sample. These composite samples were brought to analytical size by the quartering method (JnNURM, 2012). For estimating persons per housing unit, a questionnaire survey was conducted in the selected colonies. Per capita waste generation was calculated by dividing the weight of the waste of all the colonies of an economic class and dividing it by the number of persons residing in the households of the colony from which the waste samples were taken.
Fig. 3.19 Course of sampling and analysis of municipal solid waste.
Sampled waste was hand sorted into the following 8 categories:

1. Compostable/Putrecibles - Food waste, yard waste, leaves.
2. Inert- Pebbles, ground, construction and demolition wastes.
5. Leather and synthetics-Raxine, shoes, belts etc.
6. Textile and synthetics- Dress material waste, napkins, nappies, sanitary napkins.
7. Glass- All kinds and colors.
8. Metals- Both ferrous and non-ferrous
Raw weight of each ingredient was measured to figure out the wet-based content of each ingredient. The weight of individual ingredient was taken and its fraction was represented in terms of percentage (%) of the total wet weight of municipal sample taken (American Public Health Association (APHA), 1989). The determination of bulk density, moisture and dry density has been performed as per procedure is given in Bureau of Indian Standard (BIS) (2013).

The dumpsite characteristics of waste are considered most useful as it is the source feed material for the establishment of the treatment project for the municipal waste. The composition and characteristics of the waste determine the type of treatment method to be adopted. Bulk density, moisture content, dry density, calorific value and C/N ratio of dumpsite waste, was determined. Ten samples of 10 kg each were collected separately, mixed and brought to analytical size by quartering method.

1. **Bulk density**

   The bulk density was obtained by dividing the weight of the sample by volume of the container containing sample after compacting using equation 1.

   \[
   \gamma = \frac{W_2 - W_1}{V} 
   \]

   \(\gamma\) = bulk density (gm/cm\(^3\)), \(W_1\) = Wt. of empty container in gm, \(W_2\) = Wt. of the container with the sample in g, \(V\) = Volume of container up to which the sample is present in the cylinder after compaction.

2. **Moisture**

   The percentage moisture in the sample was determined by following equation 2.

   \[
   m = \frac{B - C}{B - A} \times 100
   \]

   \(m\) = moisture content (%), \(A\) = Mass of empty Petri dish (gm), \(B\) = Mass of the Petri dish with sample before drying (gm), \(C\) = Mass of Petri dish with sample after drying at 70\(^\circ\)C for 24 hrs.
3. **Dry density**

It was estimated using bulk density and moisture content by following equation 3.

\[ \gamma_d = \frac{\gamma}{1 + m} \]  
\[ (3) \]

\( \gamma_d \) = dry density (gm/cm\(^3\)), \( \gamma \) = bulk density of substance (gm/cm\(^3\)), \( m \) = moisture content (%)

4. **Calorific value (CV)**

Bomb calorimeter was standardized by igniting benzoic acid of known calorific value in oxygen sealed bomb. By igniting benzoic acid, water Equivalent (W) is evaluated. After evaluation of water equivalent, the same value of W is substituted in the equation for determining the calorific value (Equation 4) of the samples (CVs).

The water equivalent of the system was determined by igniting a pellet of pure benzoic acid of known calorific value weighing not less than 0.8 and not more than 1.1 gram and recording the temperature rise (T). Water equivalent was calculated by substitution of values in the equation.

\[ W = \frac{6319 \times A + (E_1 + E_2)}{Temperature \ rise} \]

Temperature rise = 2.69 Degree

Calorific value of Benzoic acid = 6319 cal/g

\( A \) = Sample weight (g)

Weight of thread = \( x \) mg x 4.18 cal/mg = 76.49

\( E_1 \) = Calorific value of thread

Weight of total wire = \( Y \)

Weight of wire after burning = \( B \)
Y - B = C

E2 = Calorific value of wire

E2 = C x 0.335 cal/mg

Calorific value = $W \times \frac{\text{Temperature rise} - (E1 + E2)}{\text{Sample weight}}$ (4)

5. C/N ratio


Organic Carbon determination by Walkley-Black Method-

Weigh 1 gm of 0.5 mm sieved solid waste into dry 500 ml conical flask. Add 10 ml of K$_2$Cr$_2$O$_7$ into the flask with pipette and swirl. Add rapidly with a burette 20 ml conc. H$_2$SO$_4$ and swirl gently until the waste and reagent are mixed then more vigorously for one minute. The reaction proceeded for 30 minutes on the asbestos sheet to avoid burning of the table due to the release of intense heat due to the reaction of sulfuric acid. 200 ml of distilled water, 10 ml of concentrated orthophosphoric acid and 0.2 g NaF added. Allow the sample to stand for 1.5 hrs. The titration end point is clear in a cooled solution. Just before titration 1ml, ferroin indicator was added into the conical flask. Titrate the excess K$_2$Cr$_2$O$_7$ with 0.5 N ferrous ammonium sulfate till the color flashes from yellowish green to greenish and finally brownish red at the end point. Simultaneously blank was run without waste.

Calculations-

\[
\% \text{ Organic carbon} = (B - S) \times N \times 0.003 \times \frac{100}{Wt. \text{ of waste (Oven dry)}}
\]

Where,

B = ml of std. 0.5 N ferrous ammonium sulphate required for blank.
S = ml of std. 0.5 N ferrous ammonium sulphate required for the waste sample.
N = Normality of std. ferrous ammonium sulphate (0.5N).
The correction factor 1.3 is multiplied as according to Walkley and Black method only estimated 77% carbon (av. Value). The result can be converted to corrected total organic carbon by multiplying the factor 100/77 = 1.3 Waste organic matter contains (58%) of organic carbon, the percentage of organic carbon multiplied by 100/58 = 1.724 which gives the percentage of organic matter i.e.

Organic matter = Organic Carbon x 1.724

Total Nitrogen
Take 20 gm of sieved waste into 1 liter round bottom flask. Add little-distilled water with the help of jet in such a way that the particles of waste do not remain stuck to the sides of the flask. Add 2 to 3 glass beads to present bumping and 1 ml of liquid paraffin to prevent frothing. Add 100 ml of potassium permanganate and 100 ml of sodium hydroxide solution to the flask. Distil and collect the distillate in a beaker contains 20 ml of boric acid working solution. Collect approximate 150 ml of distillate. Titrate the distillate with standard H₂SO₄ 0.02 N till the color changes from green to red and records the burette reading. Carry out blank without waste.

\[
\text{N} \% = (A - B) \times \text{Normality of H}_2\text{SO}_4 \times \text{Equivalent weight of N} \times \frac{100 \text{ gm}}{\text{Wt. of waste sample}} \times \frac{1}{100 \text{ to convert N mg into g}}
\]

A = Volume of H₂SO₄ required for waste sample
B = Volume of H₂SO₄ required for blank

3.2.5 Population and density calculations
1. Gross population density

\[
\text{Gross population density (Person/m}^2\text{)} = \frac{\text{Population}}{\text{Area of Block}} \quad (5)
\]

2. Net population density

\[
\text{Net population density (Person/m}^2\text{)} = \frac{\text{Population}}{\text{Residential built up area of Block}} \quad (6)
\]

3. Net waste generation density
Net waste generation density = \frac{\text{Waste generation}}{\text{Residential built up area of block}} \quad (7)

### 3.2.6 Soil permeability and groundwater depth survey

Data to be used in the model has to be of the scale appropriate for the application. Data regarding the depth of water table and soil permeability was not available from any source to the micro scale required for the application, therefore, data regarding this parameter in the study area was generated through survey and sample analysis. For the collection of the soil samples and survey for groundwater depth, the sampling sites were selected. A grid type sampling of the study area was done by preparing a fishnet having grids of 1 Km\(^2\) (Fig.3.6) using spatial analysis tool of GIS. Samples were collected/survey done as far as possible near the centroid of each grid using GPS. Soil samples were tested for permeability as described in sub-section 3.2.7. For the survey of groundwater table depth, the owner of tube wells and hand pumps were questioned about the depth at which ground was available. After determining the permeability of the soil samples and survey of the groundwater depth from each grid of the fishnet the data was registered as attributional data of each grid. But as per the requirement of the GIS models used here for dumpsite suitability analysis data is required in raster form meaning that each pixel has to have a value for each of the parameters. In order to assign values of the parameters to each pixel the interpolation of the values obtained from sample analysis of soil for permeability and values obtained for ground water depth from the survey were used in the Spatial Analysis tool of GIS the application “Interpolate to Raster”. Interpolation technique of Kriging was applied and the Raster data so generated for each parameter was used in the Model for site suitability analysis for dumpsite selection.

**Soil Permeability**-

Soil permeability was estimated through “Falling head method”.

**Principle**

In this method, drop in water level in a narrow tube is measured instead of flow.

The drop of height \(dh\) of water in time \(dt\) in a narrow tube of cross-sectional area ‘\(a\)’, inverted over a saturated soil whose cross-sectional area is ‘\(A\)’, and length, ‘\(L\)’. 
The flux $dq$ in time $dt$ will be

$$dq = a \cdot dh$$

In terms of Darcy law

$$dq = -K \cdot A \cdot dt \cdot (h/L)$$

From equations (i) and (ii)

$$K \cdot A \cdot dt \cdot (h/L) = -a \cdot dh \text{ or } dt = -a \cdot (dh/h) \cdot K \cdot A$$

Integrating between $t_1 h_1$ and $t_2 h_2$ gives

$$K = (aL/At) \ln (h_1/h_2)$$

**Apparatus**

Special apparatus (Fig. 3.20) consists of a galvanized iron cylinder with a conical top to which a vertical glass tube of small diameter is attached.

**Procedure**

Push the cylinder into the soil to a depth for which determination is to be made and assemble the whole apparatus. Wet the sample water through a three-way stop cock and lower porous plate. Fill the space above the sample by introducing water with pipette or syringe at the top of the sample until it overflows. Record the time for the water level to fall from $h_1$ and $h_2$ make additional 2-3 such measurements.

![Fig. 3.21 Falling head permeameter.](image-url)
Observations and calculations

Diameter of standpipe = d cm
Cross-sectional area of standpipe = a cm$^2$
Length of the sample = L cm
Diameter of the sample = D cm
Cross-sectional area of the sample = $\pi r^2$, A cm$^2$
Initial hydraulic head = $h_1$ cm
Final hydraulic head = $h_2$ cm
Time is taken for change in head = t s
Saturated hydraulic conductivity = $(a L/At) \ln (h_1/h_2)$ cm s$^{-1}$