



# Potential landfill site suitability study for environmental sustainability using GIS-based multi-criteria techniques for nashik and environs

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## Abstract

Suitability study for potential landfill sites and Solid Waste Management (SWM) is one of the major challenges for city planners. This study was conducted for the upcoming scientific waste management site of Nashik and Environs, Maharashtra, India. As the state nominated the city for the National Smart Cities Mission, the existing landfill site is on the verge of closure. This study aims to identify spatially suitable potential landfill sites. Study based on remote sensing and geographical information system techniques with multi-criteria decision analysis. It considered environmental, socio-economical, and technical criteria to maintain sustainability and improve the standard of living of people nearby vicinity. Fifteen parameters were considered while selecting a potential landfill site. A constructed analytical hierarchy process (AHP) with a consistency ratio of 0.05557 was used to evaluate the weightage of the nine parameters. Restriction buffer analysis was performed on the four parameters, and restricted zones were omitted. For potential site selection, a threshold limit and selection criteria were used. The study identified several potential landfill sites and their suitability within the wasteland. The required landfill area for the coming years is calculated based on the projected population, and the potential landfill site map shows the effectiveness of the proposed method. This systematic study will assist city planners in identifying potential landfill site suitability for environmental sustainability during the selection process.

**Keywords** Solid waste management (SWM) · Landfill · Environmental sustainability · GIS · AHP

## Introduction

Municipal Solid Waste (MSW) generation is increasing, resulting in environmental degradation and pollution. India generates 0.1 million tonnes of solid waste per day, with that figure expected to rise to 33 percent in the next 15 years (Endait and Patil 2020). Because of population growth and the gradual expansion of cities. The area required to dispose of solid waste increases and results in an unfortunate lack of basic infrastructure facilities for MSW disposal (Hannan et al. 2015). The effective management of solid waste realistically is a difficult task for city planners, particularly in urban areas. It invariably includes social, environmental, and financial aspects. The complex hierarchy of solid waste management (SWM) often includes prevention, minimization, recycling, reuse, recovery, and reduction. However, proper disposal efficiency is the least favorable option for solid waste. Most of the diplomatic initiatives were promptly taken for the reduction of waste at source and source segregation. Despite that, the critical problem is in handling and safe disposal at the potential landfill site. MSW is typically

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used for energy recovery, composting, and recycling, but the rejected inert material is sent to the scientific landfill for degradation (CPHEEO 2016).

In India, Landfill sites shall be set up as per the Ministry of Housing and Urban and Central Pollution Control Board guidelines. The conventional landfill identification method follows criteria for site selection which includes the following: (i) setting up locational criteria, (ii) identification of search area, (iii) drawing up an intended list of potential sites, (iv) data collection, (v) selection of best-ranked sites, (vi) environmental impact assessments, and (vii) final site selection and land acquisition (PCLS/02/2021-2022) (CPHEEO 2016).

Remote sensing (R.S.) is the measurement of the energy emitted from the Earth's surface used to collect spatial data. In contrast, Geographical Information System (GIS) is used for spatial analysis. GIS-based decision analysis tools help resolve the potential problem adequately and suggest suitable sites through mapping (Sumathi et al. 2008, Dereli and Tercan 2021). The potential application of GIS employing spatial data, attribute data, and many modern researchers are using Multi-criteria Decision Analysis (MCDA) for comparative analysis of the most appropriate potential landfill sites. MCDA is a sub-discipline of operations research that explicitly evaluates multiple conflicting criteria in decision making. MCDA techniques alone and in combination with other techniques have been accepted by many prominent researchers for the proper identification of suitable waste disposal sites using different criteria. Prevalent MCDA methods practiced in the extensive literature are the analytic hierarchy process (AHP), fuzzy logic, dynamic modeling, analytical network process. A Few important methods are succinctly summarized by Patil and Endait (2021), Kharat et al. (2016).

Effective AHP technique was convincingly shown by Everett et al. (1996) for MSW landfill sites in Oklahoma. The published study considered various contributing factors of hydrogeology/geology, land use, and proximity for decision ranking, and sensitivity was checked. Kontos et al. (2005) accurately identified the MSW landfill site in the North Aegean Sea, Greece, and considered hydrology/hydrogeology, environmental, social, & technical/economic factors. Sumathi et al. (2008) used GIS-AHP & overlay analysis model for Pondicherry city. Various factors like lakes and ponds, rivers, water supply sources, groundwater table, groundwater quality, infiltration, air quality index, geology, fault line, elevation, land use, habitation, highways, sensitive sites are considered for site selection. Sharifi et al. (2009) found a sanitary landfill sitting in Kurdistan Province, western Iran, for hazardous waste from the fifteen landfill sites. The published study typically focused on local geology, hydrology, climatology, and eco-sociology factors. Moeinaddini et al. (2010) used AHP in a unique combination with the weighted linear method & GIS at Karaj, Iran. AHP

& GIS technique was used for inert landfills by Geneletti (2010) at Sarca's Plain, in southwestern Trentino. The ranking was normally based on visibility, accessibility, and dust pollution. Tavares et al. (2011) identified landfill siting for incineration plants in Cape Verde and assigned 75% weight to non-environmental factors and 25% to environmental factors. Sisay et al. (2021) employed a GIS-based multi criteria evaluation method to map the optimum suitable landfill sites in Gondar town, Ethiopia.

Ozkan et al. (2019), in their review paper, adequately explained the use of GIS & MCDA in landfill site suitability. Study reviews on specific GIS software, application area, key decisions under the ideal condition of certainty and uncertainty applied MCDM techniques, considerable sizes of the cells in GIS, and evaluation criteria. It was observed that the environmental criteria had been provided more importance. Tercan et al. (2020) found landfill identification in Turkey using GIS & MCDA. The authors adequately considered topographic, meteorological, geomorphological, hydrological, economic, and social landfill identification factors. AHP-WLC in combination with GIS was found effective and systematic in landfill site suitability. Sisay et al. (2021) found a new landfill site with the help of GIS & MCDA in Ethiopia and found that 4.5% of the study area is eminently suitable for the landfill site. The authors focused on substantial and socio-economic factors. The overall literature succinctly summarizes the method for the new landfill disposal site traditionally using the GIS & MCDA techniques. Many leading researchers focus on the specific criteria of environmental, social & technical. Very few were carefully considered the socio-economic, political, technical & scientific study of new landfill siting. In conclusion, the decision of stakeholders is very much significant in landfill identification.

In the potential landfill site selection for waste management, different criterion needs to be considered. Bilgilioglu et al. 2022 found a GIS-based MCDA techniques effective in resolving these problems and suggest a suitable landfill siting. Several MCDA techniques are available in the literature. However, some of them are feasible in decision-making. Each method has its pros and cons. To achieve accuracy in the research, a combination of two or more different methods can be used. The most frequently used combination was AHP with other techniques (Getahun et al. 2020, Kazuza et al. 2021, Kaliraj et al. 2015).

Moreover, AHP is found best from a set of available techniques and gives the accurate solution to the decision-makers because of simplicity in pairwise comparisons, Consistency in evaluation, and versatility (Ali et al. 2021). Multiple criteria are used for the comparison matrix on a random basis. There are chances of inconsistency; if the calculated consistency value exceeds 0.1, then the standard

AHP process needs to be reviewed for Consistency. AHP is the scientific analysis to find the landfill site integrated with GIS provides qualitative and quantitative results. GIS provides spatial analysis, accurate mapping, high accuracy, better predictions, and restriction analysis by eliminating unsuitable areas (Kapilan et al. 2018; Aksoy et al. 2019; Patil and Endait 2021).

The landfill site of Nashik was established in the year 2000 and is presently on the verge of a closure period. It is the fundamental need of the expanded city to find the best possible landfill location for the future. The objective of the study is to support Nashik Municipal Corporation (NMC) policymakers in identifying the suitable landfill site satisfying the criteria put forth by Central Pollution Control Board (CPCB) (PCLS/02/2021-2022 2021) (CPHEEO 2016). Authors have also ensured the sustainability of other environments (such as air, water, and land) while selecting the landfill area. The study is novel for the municipal area of Nashik, as this is the first of such kind using advanced GIS technique. The integration of AHP, restriction analysis, and selection criterion made it possible to assess and evaluate potential landfill site selection parameters. Nine thematic criteria were selected for the AHP analysis, four parameters were used for restriction buffer analysis, and an aspect map with the windrose map was considered for final site selection. Population density, water bodies, and Land Use Land Cover (LULC) criteria are considered the most important socio-economic and environmental parameters in the study. Economic factors such as proximity analysis of road and water bodies, the study of a slope, drainage pattern, and waste generation estimation depicted efficient decision-making results.

## Study area

Nashik District is in the north-western part of Maharashtra, India. The city is the third most industrialized city in Maharashtra after Mumbai and Pune. The study area comprehensively covered 905.157 Sq. Km included Nashik Municipal Corporation (276.19 Sq.km) and 73 surrounding villages in an effective radius of 15 km. The location map of the study area is shown in Fig. 1. The study area has a population count of 18 million for the census year 2011, among which 15 million live in an urban area. The city is placed at 19°35' and 20°50' north latitude and between 73°16' and 74°56' east longitude. As per the department of Survey of India, the city comes under toposheet numbers 46-H, 46-L and 47-E, and 47-I.

At present, 550 to 600 tonnes of MSW is typically collected from 2.9 lakh local households, 1806 local hotels & restaurants, and 300 commercial establishments of 108 wards. The projected quantity of MSW genera-

tion gets 1628 tonnes per day, henceforth the total quantity generation 594,220 MT per year up to 2031. Out of the generated quantity of MSW, 89,133 metric tonnes will be sent to a sanitary landfill. Endait and Patil (2020) showed the complex characterization of incoming Fresh MSW of Nashik city, containing 11% of non-biodegradable components. The remaining was categorized as easy, medium, and hard biodegradable components. Hence, there is a social need to invariably find new landfill sites for the proper disposal of MSW for Nasik city with practical consideration of environmental, social & economic factors.

## Data and software used

Graphical and attribute data sources were used for the site suitability analysis. GIS application tools, ArcGIS 10.7.1 and ERDAS Imagine 2018, were used in this study. Geo-referenced and corrected data of level II of Resourcesat-2A of the LISS IV, a high-resolution multispectral camera with a 5.8 m spatial resolution, was adopted (Table 1). The multispectral image is better for LULC classification; therefore, primary satellite data was used for supervised classification. Rabi and Kharif season data were used for visual interpretation and accuracy assessment. To enhance the visual interpretation, pre-processing operations like satellite image mosaic and sharpening were done using ERDAS. The ArcGIS 10.7.1 was used to prepare the LULC map, key generation of thematic maps, proximity analysis, reclassification, weighted overlay analysis, and final site suitability maps. Digital Elevation Model (DEM) acquired from CartoDEM of 30 m spatial resolution from BHUVAN geoportal of NRSC. Secondary data include Geomorphology, Hydrogeology, and Lineament maps, were sourced from concerned departments of NRSC.

## Methodology

The current study's methodology included selecting a potential landfill site using integrated AHP, restriction analysis, and site selection criteria. The developed methodology used in this study is shown in Fig. 2. For comprehensive AHP analysis, nine thematic layers were used; geomorphology, hydrogeology, distance to road, drainage, lineament, slope, LULC, distance to water bodies, and population density. As shown in Table 2, the airport, water bodies, road, and local habitation were used for restriction buffer analysis and aspect, windrose diagram for final site selection. A subsequent section of the study described in detail data collection, thematic map generation, and processing methods for

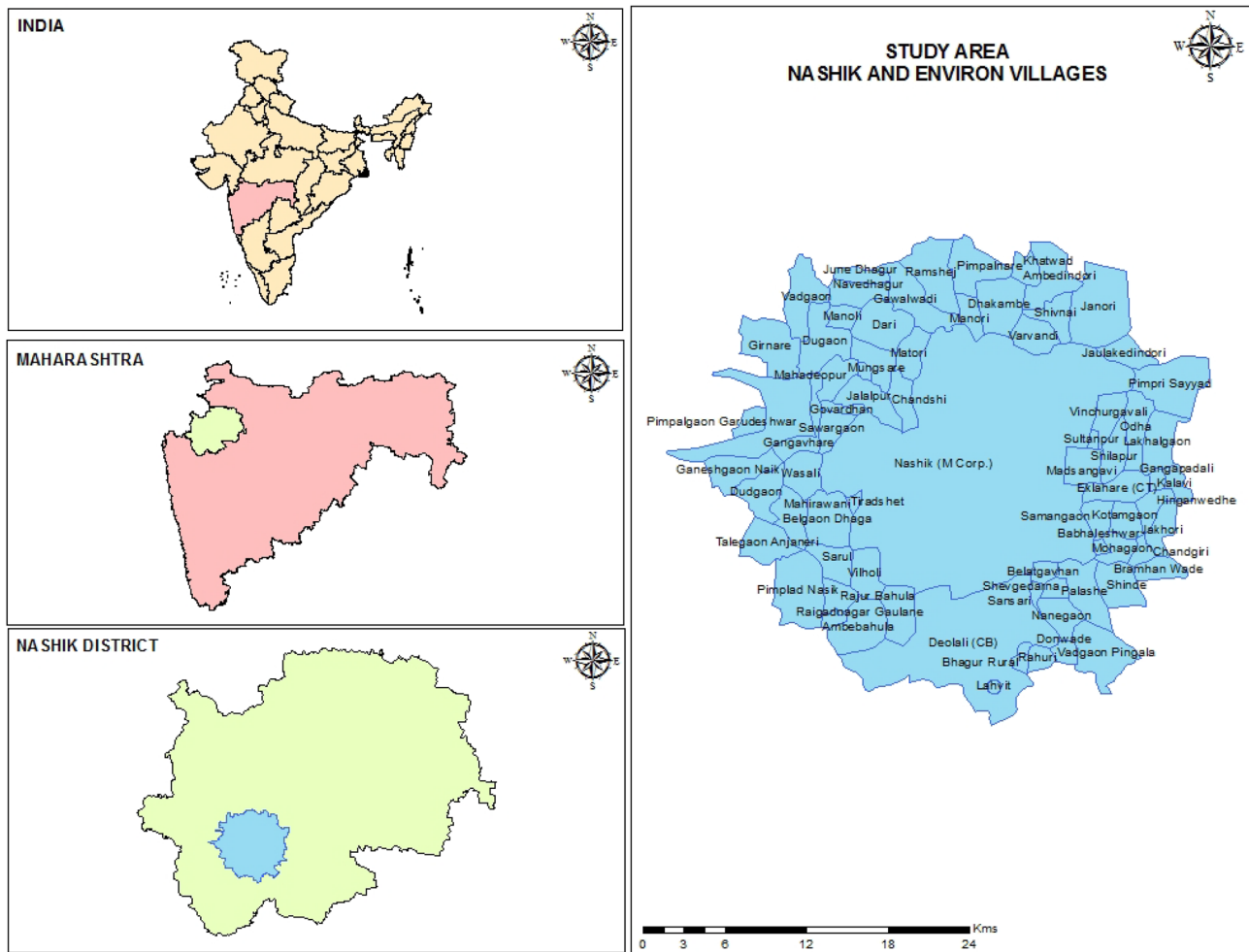


Fig.1 Location map of the study area

Table 1 Satellite data used in the study

Satellite	Sensor	Date of acquisition	Spatial Resolution	Spectral Resolution
Resourcesat-2A	LISS IV	18 October 2018	5.8 m	3 Bands
Resourcesat-2A	LISS IV	18 January 2019	5.8 m	3 Bands
Cartosat-1 DEM	PAN	29 April 2015	30 m	–

Source: [www.isro.gov.in/bhuvan.nrsc.gov.in](http://www.isro.gov.in/bhuvan.nrsc.gov.in)

potential landfill site selection by advanced GIS-MCDA techniques.

Resourcesat-2A multispectral data of sensor LISS IV had 5.8 m resolution on a scale of 1:10,000, geocoded with UTM projection spheroid and datum WGS 84 zone 43 north received from NRSC's user order processing system. Table 1 depicts data collected on 06 August 2019 for the Rabi and Kharif seasons for 18 January 2019 and 18 October 2018, respectively. Prominent features like built-up, agriculture, forest, wasteland, and water bodies were classified. The

CartoDEM with 30 m resolution data was used to extract slope, drainage density, and aspect. The base thematic maps of Nashik and Environ, namely geomorphology, hydrogeology, lineament, and road, were collected from present data of the NRSC, based on Survey of India toposheet number (46H/12—46H/16 & 47E/9, 47E/13) which was on 1:50,000 scale. The population for 2021 was estimated by the geometrical projection method and used to create a density map. Proximity analysis is done for airports, roads, water bodies, and habitation. Restricted maps were generated per

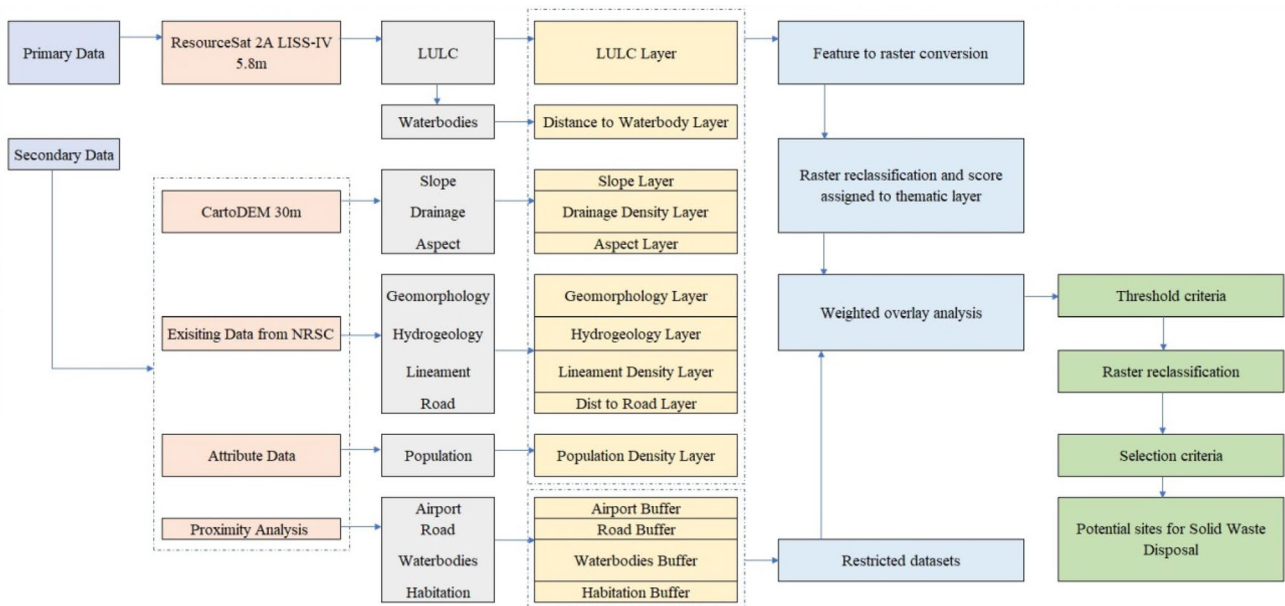


Fig.2 Schematic flow chart of the methodology

Table 2 Thematic layers used for the landfill suitability

Thematic layers	Purpose
Geomorphology	To find out the undissected landform features
Hydrogeology	To detect the area covered with massive basalt
Distance to road	To avoid the violation of laws and for aesthetic reasons
Drainage density	To avoid the contamination of leachate
Lineament density	To identify the surface fracture intensity
Slope	To minimize the excavation cost and to stop the leachate run-off
LULC	To identify the land use cover with major features
Distance to waterbodies	To avoid the contamination of leachate
Population density	To maintain healthy habits and stop a nuisance in the nearby populated areas
Airport restriction	The flight corridor and around the area must be clear of birds
Waterbodies restriction	Concern regarding run-off of wastewater contact
Road restriction	The restriction is mainly for aesthetic reasons
Habitation restriction	No-development buffer zone after the landfill location is finalized
Aspect	To get the balanced exposure and surface inclination towards the radiance of sunrays
Windrose	To avoid adverse effects due to air pollution

the SWM guidelines issued by the CPCB in PCLS/02/2021-2022 and the CPHEEO manual of 2016. The windrose diagram was developed for the wind flow and wind direction assessment. The data source for the windrose formation was taken from the control room for air quality management of CPCB.

All thematic maps were efficiently converted into rasters with a common resolution of 5.8 m, and then the raster maps were reclassified based on the rank of the parameters. Table 3 shows the percentage weights assigned to each parameter of each thematic map, and weights were assigned

using the pairwise consistent AHP matrix. The suitability map shown in Fig. 6a was created by overlaying all of the thematic maps in the weighted overlay analysis in the ArcGIS environment. In combination with the restricted layer, weighted overlay analysis produced the output as potential landfill areas, further scrutinizing with threshold criteria based on the suitability score assigned and area requirement. As a result, raster maps were reclassified according to their suitability for landfill site selection. The final potential sites selection was determined by examining the aspect and windrose map for Nashik and environs.



**Table 3** AHP pairwise comparison matrix and computed weights of each parameter

Factor	A	B	C	D	E	F	G	H	I	Weights
Geomorphology (A)	1	1	0.333	0.25	0.2	0.143	0.143	0.125	0.111	0.02015
Hydrogeology (B)	1	1	1	0.333	0.25	0.2	0.167	0.143	0.125	0.02528
Distance to Road (C)	3	1	1	0.5	0.333	0.25	0.2	0.167	0.143	0.03383
Drainage Density (D)	4	3	2	1	0.333	0.333	0.25	0.2	0.167	0.05188
Lineament Density (E)	5	4	3	3	1	1	0.333	0.25	0.25	0.08758
Slope (F)	7	5	4	3	1	1	0.5	0.333	0.25	0.10379
LULC (G)	7	6	5	4	3	2	1	0.5	0.333	0.15395
Distance to Waterbodies (H)	8	7	6	5	4	3	2	1	0.5	0.21762
Population Density (I)	9	8	7	6	5	4	3	2	1	0.30592
Overall Consistency:	Consistency Index (CI): 0.08057, Consistency Ratio (CR) 0.05557									

Aspect map assisted in examining the physical slope features and direction of landfill directly to the sun exposure to avoid any possible fire incidents. At the same time, the rationale of using city-specific windrose in final landfill site selection is to prevent the transport of any airborne pollutants. Odor, transport of particulate matter, and harmful gases are frequent at landfill sites. However, this all can depend upon the overall operation and Maintenance of landfills. Landfill fires are common under Indian conditions from which harmful pollutants are transported to nearby dwellings. The same is with the issue of odor hindering the well-being and quality of living for the inhabitants. The transfer of all these pollutants is facilitated by air medium. Hence, the final site selection has inferred predominant wind direction from the developed windrose diagram to ensure no selected landfill falls within the transit. Four landfill potential site areas shown in Fig. 6c were identified and ranked the best potential landfill sites. This latest landfill site identification study for Nashik city will undoubtedly help city planners from a land acquisition point of commanding view.

### GIS-based MCDA for suitability score

MCDA is a decision-making tool used for ranking. It is used to aid in the execution of decisions and ranks actions from best to worst. As a result, stakeholders obtained a compromise solution in the chosen field of decision-making. Traditionally, the effective MCDA technique has been used in every sector where choices between alternatives are required.

For landfill site selection in the current study, techno-environmental criteria were taken into account. Saaty's (2008) ranking scale was used to rate key parameters on a scale of 1–9. The AHP analysis adequately prepared the thematic layer to operate the key parameters for economic decision-making. Typically, a score of 9 was assigned for the most importance and a score of 1 for similar or least practical importance.

### Accuracy assessment of LULC classification

The accuracy assessment of LULC classification for Nashik and environs would aid in determining the desired accuracy of classified results. Arbitrary sampling was implemented to collect 25 sample points for each class, yielding 125 samples for assessment. A Kappa-based accuracy assessment is used to compare the classification image to another data source. In this study, collected sampling points were later verified using a geospatial database on LULC prepared by NRSC under the Natural Resources Census (NRC) Project using three-season Resourcesat-2 ortho rectified LISS-III data from 2015 to 16. Traditional accuracy assessment method was followed, which includes the calculation of kappa coefficient, overall accuracy, producer's accuracy, and user's accuracy for the classified LULC map. This preventive measure of accuracy assessment is computed as (Behera et al. 2017; Verma and Raghuvanshi. 2020).

$$K_{\Delta} = \frac{N \sum_{i=1}^r x_{ii} - \sum_{i=1}^r (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^r (x_{i+} + * x_{+i})}$$

where  $r$  is the no. of rows in the matrix,  $x_{ii}$  is the no. of observations in row  $i$  and column  $i$ ,  $x_{i+}$  and  $x_{+i}$  are the marginal totals of row  $i$  and column  $i$ , and  $N$  is the total number of observations. The present study estimated the overall accuracy of 94.40% and the kappa coefficient of 0.93 (Table 4).

### Analytical hierarchy process (AHP)

AHP is an effective MCDA technique for analyzing multiple criteria in decision-making and ranking them in order of importance. To assess the suitability for landfill siting, a pairwise comparison matrix for nine thematic parameters was created. A pairwise comparison matrix was used to examine and evaluate the importance of each criterion about the others. Based on Saaty's (1980) work, this study

**Table 4** Overall accuracy assessment of LULC classification

	A	B	C	D	E	Total (User)	Reference Totals	Classified totals	Producers accuracy in %	Users accuracy in %
Waterbodies(A)	25	0	0	0	0	25	25	25	100	100
Agricultural Land(B)	0	22	0	3	0	25	25	22	91.67	88
Built Up(C)	0	0	24	1	0	25	25	24	100	96
Wastelands(D)	0	2	0	23	0	25	25	23	82.14	92
Forest(E)	0	0	0	1	24	25	25	24	100	96
Total (Producers)	25	24	24	28	24	125	125	118		

utilized an importance scale ranging from 1 to 9. Each criterion was assigned relative weights on a nine-point scale using the opinion of NRSC scientists and subject expertise, as shown in Table 5. Eigen vector value was determined for the 9×9 matrix, and relative weights were accurately calculated (Saaty 2008).

The overall Consistency was checked by calculating the consistency Index (CI) and Consistency Ratio (C.R.). In the AHP analysis, the identification of Consistency is necessary to evaluate the problem and confirm the validity of the results. The CI & C.R. value for the constructed matrix was calculated as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{1}$$

$$CR = \frac{CI}{RI} \tag{2}$$

where; λ<sub>max</sub>—is the product between each element of the weight and the column total of the comparison matrix, n—The number of parameters, R.I.- the random consistency index. R.I. is a constant parameter assigned based on the criteria considered (Saaty 2008); the R.I. value for the 9×9 matrix was assigned in the AHP model as 1.45. Table 3 shows the CI and C.R. values obtained using equations i and ii, 0.08057 and 0.05557, respectively. If the C.R. value is less than 0.1, the resulting response value has acceptable Consistency. If the achieved C.R. value exceeds this threshold, the decision in the comparison matrix is deemed inconsistent, and the process must be re-evaluated. Overall Consistency was obtained in this study as CR=0.05557, which is within the threshold. As a result, the AHP matrix is consistent, and the parameter weights can be used for weighted overlay analysis. To create a suitability map, a weighted overlay analysis was performed using the relative weights of each representing criterion. AHP was used in conjunction with GIS to determine the suitability assessment, which was further used to categorize the study area as highly suitable, not suitable, and less suitable.

## Criteria description and application

### Thematic parameters for MCDA

This study examined a total of 15 different criteria. Geomorphology, hydrogeology, distance to road, drainage, lineament, slope, LULC, distance to water bodies, and population density were used for AHP analysis. While airports, water bodies, roads, and habitations were used for restriction buffer analysis and aspect, the windrose diagram was used for final site suitability. The following sections of the study provide a detailed description of the parameters mentioned.

### Geomorphology

The geomorphology map used in the study has been classified into seven classes, namely moderately dissected, weathered, slightly dissected, waterbody, highly dissected, weathered canal command, and undissected. Geomorphological features considered in the study were directly linked to the groundwater percolation. Therefore, it was an important factor in selection, for which a highly dissected area was unsuitable, and an undissected area was the most suitable for dumping solid waste. The suitability score for geomorphological parameters depicted in Fig. 3, with undissected areas having a high score of 9 and waterbodies /weathered canal-command attained less score 1.

### Hydrogeology

The geology map used in the study provides information about the infiltration rate capacity of the Earth's surface. As shown in Fig. 3, the study area covered the following three major lithological units: massive basalt, mixed basalt, and vesicular basalt. Infiltration rate plays an important role in landfill suitability study. The rate of infiltration was high for mixed basalt, while it was poor for massive basalt. Table 5

**Table 5** Suitability score for selected criteria

Sr. No.	Name of Thematic Criteria	Reclassified concerning present Study Area	Suitability Score (1- less preferred, 9- extremely preferred)
1	Geomorphology	Waterbody/weathered-canal command	1
		Weathered	1
		Highly dissected	3
		Moderately dissected	7
		Slightly dissected	8
2	Hydrogeology	Undissected	9
		Waterbody	1
		Mixed basalt	3
		Vesicular basalt	7
		Massive basalt	9
3	Distance to the road (meter)	0–200	1
		201–300	3
		301–500	5
		501–1000	7
		> 1000	9
4	Drainage Density (Km/sq.km)	> 5	1
		4–5	3
		3–4	5
		2–3	7
		1–2	9
5	Lineament Density (Km/sq.km)	> 0.8	1
		0.4–0.8	5
		0.4	7
6	Slope (degree)	> 20	1
		10–20	1
		5–10	5
		2–5	7
		0–2	9
7	LULC	Waterbody	1
		Forest Area	1
		Built-up	1
		Agriculture	1
		Wasteland	9
8	Distance to Waterbodies (meter)	0–250	1
		251–500	1
		501–1000	3
		1001–1250	7
		> 1250	9
9	Population Density(pop/sq.km)	> 3000	1
		1001–3000	3
		501–1000	5
		251–500	7
		0–250	9

shows that the massive basalt was highly suitable for site selection with a high suitability score of 9, a low suitability score of 3 for mixed basalt, and a score of 1 for a waterbody.

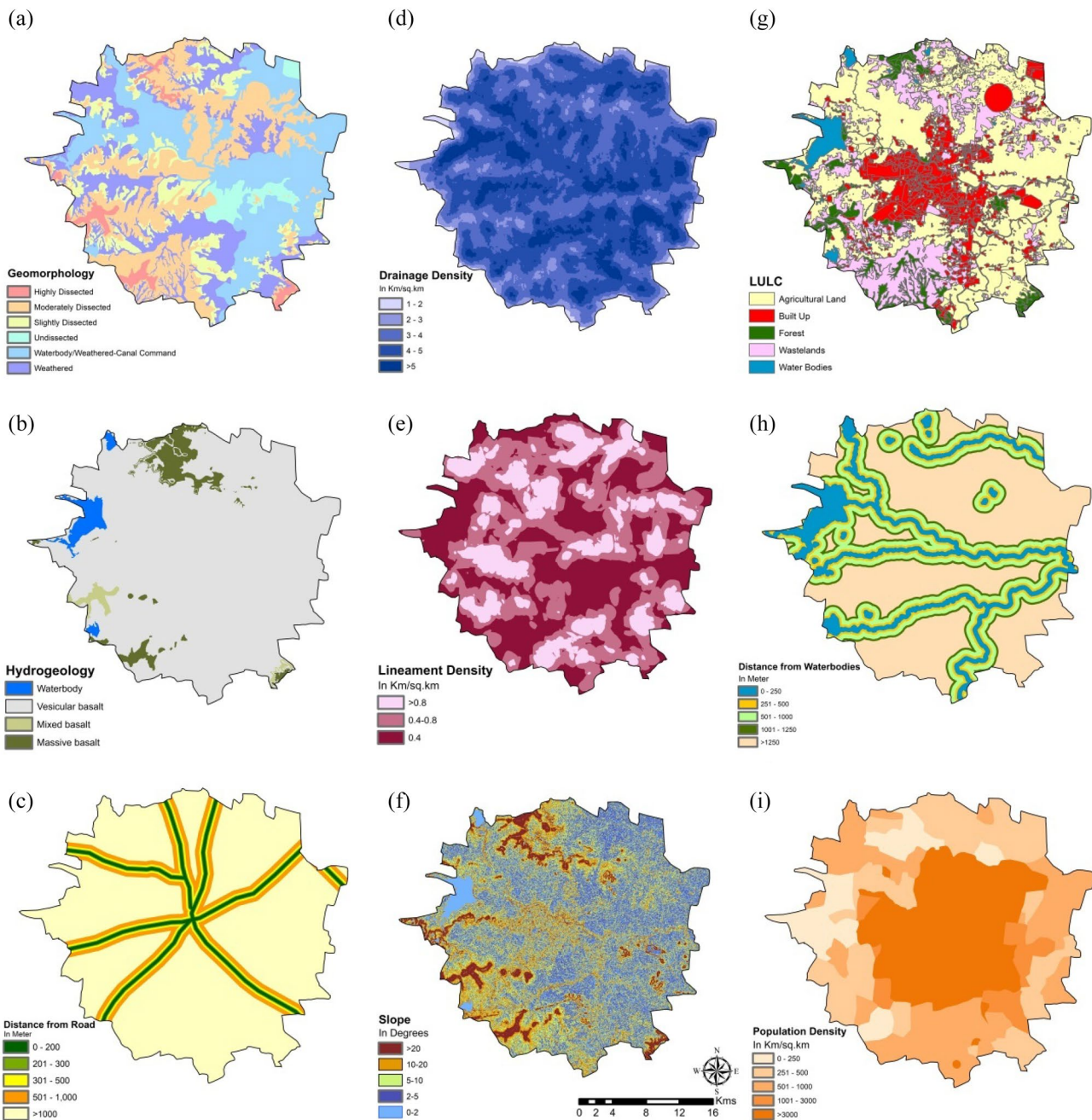
### Distance to road

The India road network data for highways and primary and secondary roads were chosen for the study area to

generate the distance to the road map. Landfill sites should be built at least 200 m away from a national or state highway. Hence, it comprised the study's socio-economic perspective. As a result, locations away from the road network received a high score. Table 2 shows that landfill locations within 0–200 m were not suitable with a score of 1 and that the most suitable score of 9 was given to a distance of more than 1000 m, as shown in Fig. 3.



## Thematic Parameters for AHP Analysis



**Fig.3** Thematic parameters for AHP analysis used in the study: **a** geomorphology, **b** hydrogeology, **c** distance to road, **d** drainage density, **e** lineament density, **f** slope, **g** LULC, **h** distance to waterbodies, **i** population density

### Drainage density

The drainage density study map depicts the stream channels found in the study area. The drainage density study provides data on surface run-off. The drainage density map produced by the CartoDEM imagery is shown in Fig. 3. The drainage density for the study area was 2.628 km per

square kilometer. Surface and subsurface formation in the study area from drainage density provides information on the region's surface run-off. Stream channel drainage density values of 1–2, 1–3 km/sq.km have fewer chances of surface run-off, whereas drainage density > 5 km/sq.km has the highest value, which tends to have higher run-off present in the area. In the study, potential drainage density areas

were unsuitable for landfills, whereas areas away from the drainage density were best suited for the landfill site. Table 5 shows that a score of 9 for lesser drainage density and 1 for higher drainage density were considered.

### Lineament density

Lineament density can be used to calculate the intensity of surface fractures. Figure 3 depicts the lineament moments in the NW–SE and NE–SW directions. It was well understood that a lower lineament density represents solid rocks with lower infiltration rates, implying that they are more likely to be suitable for waste management landfill sites. The current study area has a lower lineament density of 0–0.4 km/sq. km and a higher lineament density of > 0.8 km/sq. km. The northwest and southern parts of the study area have high to moderate lineament density, as shown in Fig. 3. Table 5 depicts the lineament density weights, with a suitability score of 7 for low density and 1 for high density.

### Slope

The slope map was created using CartoDEM satellite data, as shown in Fig. 3. Table 5 shows that it has been classified into five-degree classes, with a suitability score ranging from 1 to 9. The slope parameter plays an important role in the selection of suitable landfill sites. Higher degrees of the slope will necessitate costly excavation, and a steep slope with an excess of waste will result in a landslide. The high slope attained a suitability score of 1, while the flatter area received 9.

### Land use land cover (LULC)

The LULC map of Nashik and Environs is depicted in Fig. 3. The LULC data for the study were prepared by using LISS IV merged images of the Resourcesat-2A satellite with a spatial resolution of 5.8 m. The LULC map has been classified into the following five categories: Built-up, Agriculture, Wasteland, Forest, and Waterbodies. Agriculture accounted for 49.88 percent of total land area, followed by wasteland (20.46 percent), built-up (17.74 percent), forest

(6.07 percent), and water bodies (3.86 percent), as shown in Table 6. According to LULC data, the wasteland area was suitable for waste disposal. On the other hand, Table 2 shows that water bodies, forests, agriculture, and built-up areas were unsuitable for landfills.

### Distance to waterbodies

Waterbodies network data extracted from the LULC layer were used to create a distance to water bodies map for landfill site selection. Solid waste disposal near water bodies can pollute both surface and inland water bodies. As a result, a buffer distance of 250 m was selected as an unsuitable condition. A buffer distance of 250 m–500 m was also determined to be insufficient for preserving waterbody conditions. Therefore, the range of 500 m–1000 m was chosen as moderately suitable. According to Fig. 3, 1000 m–1250 m and above were considered suitable for solid waste disposal.

### Population density

The population density map depicted in Fig. 3 was the most important socio-economic factor in landfill site selection. For the year 2021, a population density map of 26 million people was generated. Nashik Municipal Corporation's jurisdiction is nearly overburdened with built-up and habitation. People will be harmed if waste disposal sites are located within or near these areas. It should be located away from human habitations because it is directly related to property value and health. As a result, low-density areas with little habitation were preferred for landfilling sites. The population density data were classified as having a minimum of 250 people per square kilometer and more than 3000 people per square kilometer. Table 2 shows the most suitable area with a suitability score of 7 and 9 for the lowest population density. In contrast, a population density of more than 3000 people per square kilometer has been assigned the least importance with a suitability score of 1. Sites with the lowest density and the greatest distance from the municipal corporation are unsuitable due to the high cost of waste transportation; the results are shown in Fig. 3.

### Restriction buffer analysis

#### Airport

The airport restriction map was prepared by the criteria outlined in the CPHEEO manual (2016). According to Table 7, buffer analysis was conducted at a distance of 7500 m, as shown in Fig. 4. The obtained vector polygons were converted into a raster format with a spatial resolution of 5.8 m. A viable cell was assigned a value of 1, while a restricted cell was assigned a value of 0.

**Table 6** LULC area statistics for the year 2019

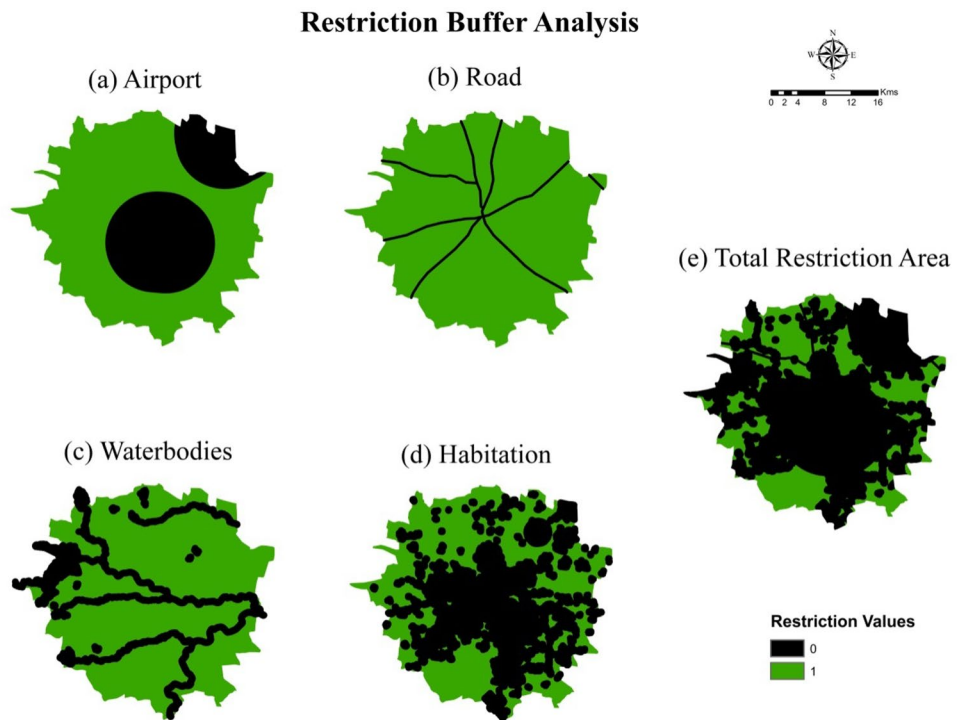
Sr. No.	LULC Classes (Level I)	Area_Sq.km_2019	Area_%_2019
1	Built-Up	178.66	19.74
2	Agriculture	451.48	49.88
3	Forest	54.924	6.07
4	Wasteland	185.18	20.46
5	Waterbodies	34.91	3.86

**Table 7** Restriction layers with their buffer analysis

Sr. No.	Restriction Layer	Min. Buffer	Max. Buffer	Analysis Buffer	References
1	Airport	5000	10,000	7500	Solid Waste Regulations; (CPHEEO 2016; PCLS/02/2021-2022)
2	Waterbodies	200	500	500	
3	Road	50	200	200	
4	Habitation	500	500	500	

All obtained restricted layers were combined using a raster calculator tool in spatial analyst to form a binary mask layer with values 0 and 1. Thus, as shown in Fig. 4, the restricted and non-restricted areas can be assigned a value of 0 and 1

**Fig. 4** Restriction buffer analysis used for: **a** airport, **b** road, **c** water bodies, **d** habitation, and **e** total restriction area



**Road**

The Road network restriction map was prepared by considering data of state highways, primary and secondary roads. According to Table 7, buffer analysis was carried out for the road network by using a distance of 200 m, as shown in Fig. 4. The obtained vector polygons of roads were converted to raster format with a spatial resolution of 5.8 m, and the restricted cell was assigned a value of 0 to nullify the zone.

**Waterbody**

The waterbody network map was created by exporting the land use land cover map of the study area. The current study area includes reservoirs, rivers, lakes, canals, and other waterbody sources. According to the solid waste management rules and locational criteria outlined in the CPHEEO

manual, the source of water and catchment area must be protected. Therefore, according to Table 7, a 500-m restricted zone was established for the study area's waterbody network to avoid contamination. The waterbody restriction map in raster format was depicted in Fig. 4, along with the area for landfill suitability.

**Habitation**

The process of habitation restriction is based on population density mapping. The data were classified into a minimum to a maximum population per square kilometer of the area; a population maximum of more than 500 people per square kilometer was limited to suitability (Table 7). Figure 4 depicts the most populated area of the Nashik, and the surroundings were restricted, and another available area was considered. Because the city center was completely



saturated, it was excluded from the analysis by assigning a pixel value of 0.

## Selection criterion

### Aspect

The aspect map was created using CartoDEM satellite data and digital elevation model tools in ArcGIS. The aspect map data displayed physical slope features and their directions. For example, the aspect map in Fig. 5 shows flat surfaces in grey with a cell value of  $-1$ . Slope directions are measured from 0 degrees north, clockwise, and return to 360 degrees north. The aspect map was classified into flat surfaces and

eight directions, and it showed the south point of view. Because India lies entirely to the north of the equator, the current study area is in the northern hemisphere, making the radiance of sun rays higher on the southern slopes. Accordingly, landfill sites were selected to get balanced sun exposure to avoid any possible fire incidents.

### Windrose

The windrose map for the period from 01/01/2017 to 30/12/2021 was used in this study for visual interpretation and final site selection. The windrose data for the study area were obtained from the CPCB portal of the central control room for air quality management. The windrose map in Fig. 5 was created using the WRPLOT View and then incorporated with the study area into the GIS environment. It was discovered that the average wind speed was 2.52 m/s, and the wind flowing from the West is determined. Wind disperses and transports air pollutants from the landfill site. It caused a risk to the surrounding areas due to pollutant diffusion. The directional risk of pollution is an important factor to consider when selecting a potential landfill site. No selected landfill will be included in the transit area in the future. As a result, the West direction is unsuitable for SWM landfill site suitability.

## Results and discussion

This study examined 15 parameters in the selection of potential landfill sites. Thematic parameters were used for AHP pairwise comparison, restriction buffer analysis, and final site suitability selection. GIS-MCDA techniques were used to create the AHP comparison matrix for nine thematic parameters. The suitability index was used to determine the identification of potential landfill sites as well as their suitability. Table 3 displays the AHP comparison matrix as well as the computed weights for each parameter. The AHP pairwise comparison matrix yields a satisfactory consistency ratio of 0.05557. Population density, water bodies, and LULC criteria were all considered important parameters in the comparison matrix. With a weightage value of 0.02015, the geomorphology map was given less importance.

To obtain better and more accurate results, the restriction buffer analysis was performed for waterbodies, habitation, airport, and the road. The obtained vector polygons were converted into a raster format with a spatial resolution of 5.8 m. All of the obtained restricted maps were combined into a binary mask layer with the values 0 and 1. It was combined in the ArcGIS spatial analyst tool with the help of a raster calculator. A value between 0 and 1 can be assigned to the restricted and unrestricted zones. As shown in Fig. 4, a restricted map of selected areas was combined into the

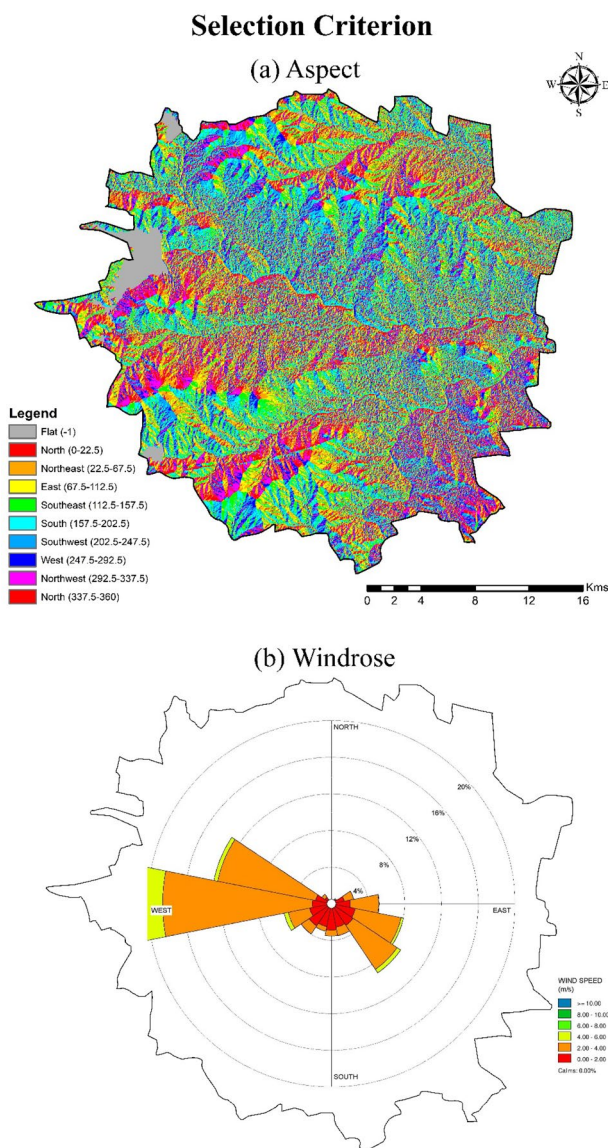
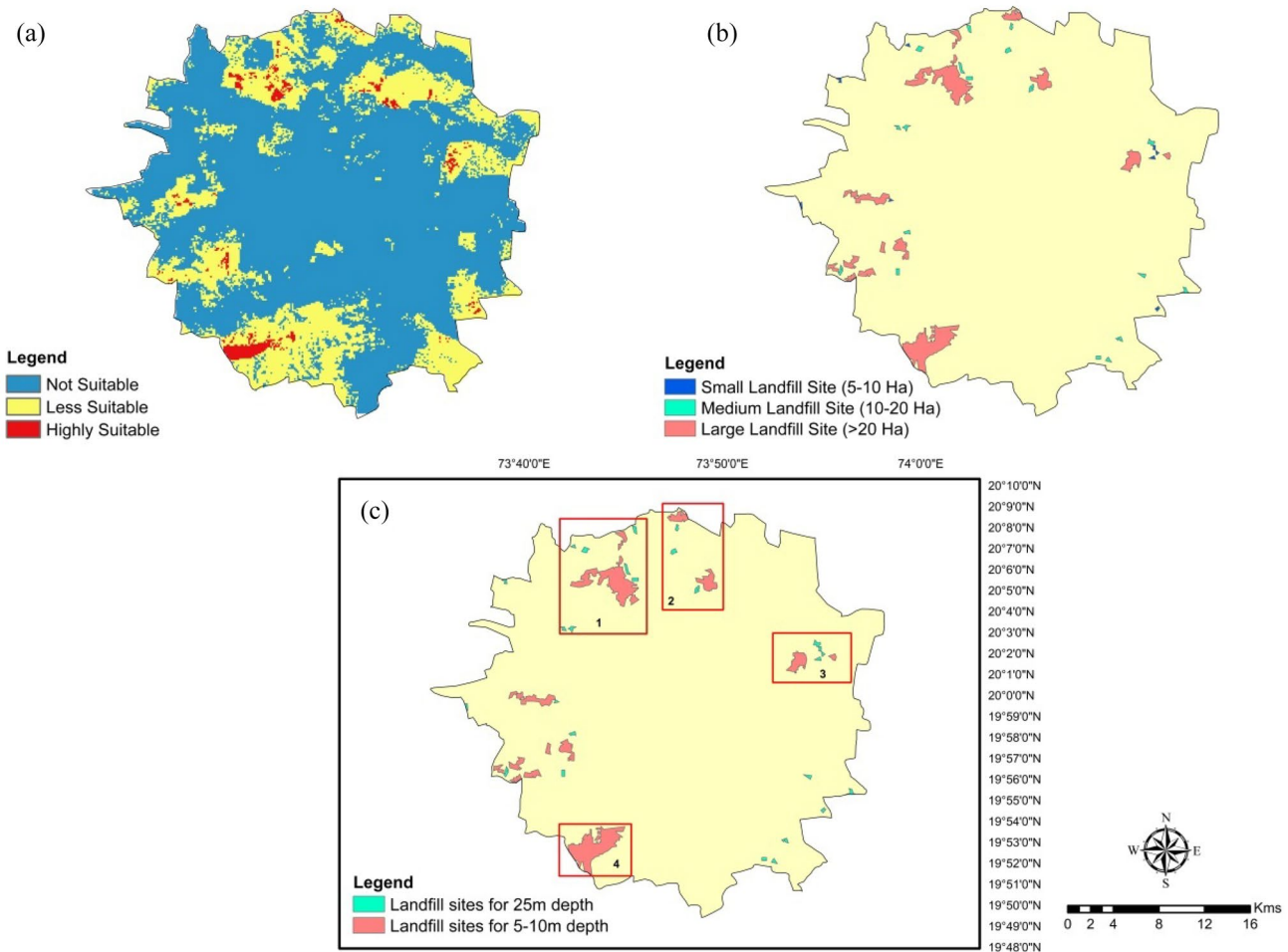


Fig. 5 Selection criterion used in the study: **a** aspect, **b** windrose

### Potential Landfill Sites for Nashik and Environs



**Fig. 6** Potential landfill sites for Nashik and environs: **a** landfill site suitability, **b** potential landfill sites, **c** selection of potential landfill sites

ArcGIS environment to generate the total restriction map of Nashik and environs. Weights calculated for the nine parameters were used in the GIS environment for weighted overlay analysis to prepare the solid waste management landfill suitability map. The resulting landfill suitability map, depicted in Fig. 6a, has been classified as unsuitable, unsuitable, or unsuitable. Because of the rapid urbanization and industrialization in the current study of Nashik and environs, the Nashik Municipal Corporation was mostly saturated, so the suitable site area obtained in the study's suitability map was away from the city area.

In 2001 (Census of India 2001), the population of Nashik and Environs villages was 13, 19,393, while it was 18, 32,427 in 2011. (Census of India 2011). The geometrical projection method was used to calculate the projected population of 26 90,352 for 2021, with the average growth rate over the last two decades being 3.915. According to the CPHEEO 2016 manual, the generation of domestic solid

waste per capita in urban and rural areas was estimated to be 0.6 kg/day. The density of compacted waste in landfill sites was estimated to be 850 kg/m<sup>3</sup>. The solid waste generated in the study area in 2021 was calculated to be 589,187,088 kg, and the waste generation volume was thus calculated to be 693,161.28 Cubic m. The height of a landfill site varies depending on the size and type of waste generated (PCLS/02/2021-2022). Cases 1 and 2 are discussed in this section. In Case 1, a coverage area of 0.139 Sq.km is required for a solid waste landfill built to a height of 5 m. Similarly, if two landfill heights of 25 m were taken into account, the coverage area would be 0.02777 Sq. Km. For final selection, the potential landfill site area at 5 and 25 m depths was calculated using a 50 percent excess, yielding 0.2085 Sq. Km and 0.041655 Sq. Km, respectively.

In the current study, two threshold criteria were applied to the obtained results to identify the most suitable landfill sites. First, the landfill site must be larger than five hectares



**Table 8** Potential landfill sites with their physiographic parameters

Site No.	Rank*	Area (Ha)	Geographical coordinates (Decimal Degrees)		Proximity coverage
			Longitude	Latitude	
1	1	782.93	73.747061	20.088423	NMC, NNW
2	1	172.19	73.822215	20.087985	NMC, NNE
3	1	16.37	73.812065	20.081761	NMC, NNE
4	1	175.26	73.897152	20.025068	NMC, E
5	1	18.38	73.913631	20.039755	NMC, E
6	2	16.06	73.792236	20.112509	NMC, N
7	2	10.50	73.795009	20.130457	NMC, N
8	2	8.504	73.916110	20.035746	NMC, E
9	3	16.07	73.759957	20.130094	NMC, NNW
10	3	58.97	73.749486	20.125957	NMC, NNW
11	3	18.90	73.718081	20.113181	NMC, NNW
12	3	102.89	73.797219	20.139317	NMC, N
13	3	22.41	73.926918	20.029437	NMC, E
14	3	13.77	73.707690	20.051025	NMC, NW
15	3	859.59	73.722647	19.877954	NMC, S.W

\*Rank: 1-most suitable, 2-moderately suitable, 3-less suitable

in size and have a weightage greater than equal to the importance value of seven. The potential landfill site map for the study area is depicted in Fig. 6. Second, final site suitability was determined through visual interpretation of selection criteria such as aspect and windrose diagram. The aspect map shows that Nashik and its surroundings were in the northern hemisphere. The radiance of sun rays was higher on the southern slopes, so that sites in the northwest and north-east directions were more suitable, as it comes under considerable condition. Because the windrose diagram depicted winds flowing from the West, sites available in that direction were neglected. As shown in Fig. 6c, a set of four potential site areas were identified. Table 8 depicted a landfill site that falls into one of the four potential zones was classified into three categories as follows: rank 1, rank 2, and rank 3. Rank 1 was determined to be the most suitable, Rank 2 to be moderately suitable, and Rank 3 to be less suitable. The results of the current methodology were useful in ranking and identifying suitable landfill sites for decision-makers.

## Conclusions

Geospatial technologies based on multi-criteria decision analysis provided an optimum result to delineate the potential landfill sites in Nashik and Environs. Suitable landfill sites for the upcoming years are obtained by considering environmental, socio-economical, and technical factors. AHP was an effective method used to estimate nine thematic

criteria' importance and determine their relative weightage. The most important parameters with the highest relative weights were determined to be population density and water bodies. In a GIS environment, a landfill suitability study was carried out using a combination of AHP and restriction buffer analysis. According to estimated data from the LULC map, the 185.18 sq. km wasteland area was available for development. The threshold criterion and waste generation per capita for upcoming years were calculated to lead to an appropriate landfill site. The consistency ratio calculated for the AHP study was 0.05557, which was less than 0.10, contributing to the chosen technique's precision. The integrated analysis of MCDA and restricted layers in the GIS environment suggested four potential landfill site areas, and the selection criterion suggested 15 potential sites around the study area. The obtained potential landfill sites were mostly in the wasteland near the municipal corporation and away from the populated places. However, solid waste handling/disposal awareness and training programs and an Environmental Impact Assessment study for potential sites need to be done.

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## Declarations

**Conflict of interest** The authors have not disclosed any competing interests.

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