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Integrating GIS And AHP For Optimal Landfill Site Selection: A Case Study of Alwar City, India

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Abstract
Municipal solid waste management (MSWM) has become a significant global and local concern. Landfill site selection is a critical component of MSWM. In various urban areas in India, including Alwar City, current dump sites were selected based on land availability rather than land suitability. This study employed Geographic Information Systems (GIS) and multi-criteria decision analysis (MCDA) using the Analytical Hierarchy Process (AHP) to classify cities into zones categorized as most suitable, suitable, moderately suitable, less suitable, and unsuitable for landfill sites. The findings revealed that 33,915 hectares, constituting 88.92% of the area, were classified as unsuitable, while 3,962 hectares (20.37 %) were considered suitable overall. Only 1,257 hectares, representing 3.2% of the total area, were the most suitable for landfill sites. A total of 121 potential sites were identified; however, only 10 met the minimum size criterion of 20 hectares and aligned with the Alwar City Master Plan 2051. The study also revealed that the existing landfill is located in an area that falls into a moderately suitable category. This study also contributes to the existing literature on choosing landfill sites that are both scientifically and socially acceptable in developing nations. This study combines MCDA, AHP, and GIS techniques to improve the environmental and socioeconomic sustainability of landfill site selection and management, thereby supporting the attainment of Sustainable Development Goals (SDGs) 3, 6, and 11.

Keywords: *Municipal Solid Waste Management, Landfill Sites Suitability, Geographical Information System, Multi-Criteria Decision Analysis, Analytical Hierarchy Process.*

Introduction
Municipal solid waste (MSW) generation is becoming a global environmental concern with significant implications for public health, environmental degradation, and climate change (Joshi & Ahmed, 2016). The World Bank report "Waste 2.0" highlights that the generation of municipal solids is predicted to grow from 2.1 billion tonnes per annum in 2023 to 3.8 billion tonnes by 2050 (Beede & Bloom, 1995). In India, the country generates around 160,038.9 tonnes per day (TPD) of solid waste, of which approximately 152,749.5 TPD was collected, reflecting a collection efficiency of 95.4% (CPCB Annual Report, 2022). Of the collected waste, 79,956.3 TPD (50%) was treated, while 29,427.2 TPD (18.4%) was sent to landfills (CPCB Annual Report, 2022). However, 50,655.4 TPD, or 31.7% of the total waste generated, remains unaccounted for (CPCB Annual Report, 2022).
This enormous amount of MSW generation is influenced by various factors such as GDP growth, rapid urbanization, population growth, tourist flow, and industrial expansion (Srivastava et al., 2015; Yatoo et al., 2024; Zambrano-Monserrate et al., 2021). This enormous increase in the generation of municipal solid waste poses serious challenges for waste management systems, especially in developing countries worldwide (Pal & Bhatia, 2022). Thus, to overcome the challenges posed by MSW, the need to adhere to the principle of integrated solid waste management (ISWM).
Integrated solid waste management (ISWM) is a comprehensive waste management process that aims to optimize waste management by focusing on both physical components (collection, disposal, and recycling) and governance aspects (inclusivity, financial sustainability, and sound institutions) (Wilson et al., 2013). The United States Environmental Protection Agency (EPA) has delineated the main elements of the ISWM as (1) source reduction, (2) recycling and composting, (3) combustion (waste-to-energy facilities), and (4) landfills. The ISWM shows that the waste management hierarchy starts by reducing waste from the source to collection, recycling, segregation, treatment, and the end of the landfill. The landfill comes at the end of the final stage, and the least attention has been paid to it (Gbanie et al., 2013).
Improper landfill siting can have significant environmental impacts, such as air, water, and soil pollution, as well as harm-sensitive ecosystems (Bojórquez-Tapia et al., 2005). Socially, it can lead to public opposition, conflicts within communities, and the community's well-being and economic conditions (Asfaw et al., 2024; Gallagher et al., 2008).
The multitude of challenges MSW poses and the identification and allocation of appropriate sites for waste disposal have become crucial for managing municipal solid waste (MSW) (Gbanie et al., 2013). The main objective of finding an optimal site for waste disposal is to mitigate the adverse effects of MSW on the environment, ecology, and economy (Chang et al., 2008).

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The selection of a landfill site is a complex, multi-criteria process that requires careful assessment and evaluation of various factors to minimize environmental and public health risks and optimize available resources (Djokanović et al., 2016). Thus, conducting an in-depth evaluation and making informed decisions regarding landfill site selection is critical for achieving sustainable and environmentally responsible solid waste management.

Various studies have found that integrating various disciplines, such as environmental science, hydrogeology, sociology, economics, and engineering, can help determine optimal landfill sites. Kontos and Komin in (Kontos et al., 2005) incorporated socioeconomic and environmental variables to determine an appropriate landfill site for solid waste disposal. While Kharat and others in (Kharat et al., 2016) identified sensitive areas and intra-municipal factors as the top two significant influences. While Sumathi in (Sumathi et al., 2008) has incorporated geological, environmental, and socioeconomic factors, and Djokanovic and others in (Djokanović et al., 2016) found geological engineering criteria to be the most important, followed by hydrogeological and hydrological criteria. However, the traditional method of landfill site selection is insufficient because of the complex and multi-criteria evaluation processes involved. It requires knowledge of many criteria, parameters, regulations, and simultaneous evaluations (Djokanović et al., 2016; Yildirim, 2012).

However, advancements in geospatial technologies, such as Geographic Information Systems (GIS) and remote sensing, have helped significantly address challenges in solid waste management (Suleman & Baffoe, 2017). However, applying GIS and remote sensing techniques can pose difficulties in harmonizing expert knowledge with public perceptions (Boroushaki & Malczewski, 2010). Thus, owing to the complexity of decision-making for landfill site selection, Multi-criteria Decision Analysis (MCDA) is a valuable methodological approach (Aksoy & San, 2019; Gbanie et al., 2013).

This approach facilitates decision-making by turning a problem into smaller, manageable components and allowing for a systematic evaluation of each criterion before integrating them into a broad framework for overall analysis (Demesouka et al., 2014; Mvula et al., 2023). Various MCDA methods, such as the Analytic Hierarchy Process (AHP), TOPSIS, and PROMETHEE, are now commonly used with GIS for site selection (Hashemkhani Zolfani et al., 2018)

These methods allow the consideration of multiple criteria, including spatial and non-spatial factors, while simultaneously providing sound data analysis at the spatial level (Demesouka et al., 2014). Various studies on the integration of GIS and MCDA for landfill site selection have been conducted in Iraq (Alanbari et al., 2014; Alkaradaghi et al., 2019), Iran (Azadeh et al., 2013; Feizizadeh & Ghorbanzadeh, 2017; Kharat et al., 2016), Norway (Barton et al., 2019), Serbia (Djokanović et al., 2016), Southern Sierra Leone (Gbanie et al., 2013), Macedonia (Gorsevski et al., 2012); Guwahati, India (Hazarika & Saikia, 2020); Roorkee, India (Jain & Subbaiah, 2007), Azarbaijan (Jamshidi et al., 2015), India (Mushtaq et al., 2020), Thailand (Thungngern et al., 2015), Turkey (Yesilnacar et al., 2012; Yildirim, 2012), and Zambia (Mvula et al., 2023). Most studies are outside India, mainly in the Middle East or Europe. Only a few studies have been conducted in India, such as Guwahati and Roorkee. According to the Ministry of Urban Government of India, in India, where more than 60 cities are million plus, 40 percent of its urban population resides in tier 2 and tier 3 cities (Annual Report, 2022). However, there is limited application of GIS and MCDA for landfill site selection, specifically in the state of Rajasthan, and none of the cities has integrated GIS and MCDA in landfill site selection, rather than based on convenience for city administration.

In the last two decades, the problem of solid waste management in Indian cities has become complex, similar to that in fast-growing industrial cities (Gupta & Gupta, 2015). The rise in municipal solid waste in Alwar City can be attributed to factors such as a 22.7% surge in population in the last decade, swift industrialization, migration into urban areas, inadequate urban planning, and insufficient capital investment in this sector. This research is driven by the urgent requirement to assess the appropriateness of a landfill location through the established scientific approaches of integrating MCDA and GIS in Alwar City and to provide evidence-based insight for sustainable landfill site management. The city has an existing landfill site operated by the Alwar Municipal Corporation. However, this dumping site's selection is mainly based on land availability and administrative convenience and not on scientific parameters regarding environmental, social, and infrastructural aspects. The National Green Tribunal report regarding Haider Ali versus the Commissioner of Nagar Nigam, Alwar, and others emphasizes issues such as open dumping, inadequate operation of processing plants, unpleasant odours near highways, and a significant risk of groundwater pollution.

Based on the literature review, it is evident that most studies have combined GIS and MCDA, and other techniques have been conducted outside India. In India, there is limited literature on the application of GIS for solid waste management. Regarding the state of Rajasthan, where Alwar City is situated, literature exists only for the status of waste collection and types of waste. Thus, the primary aim of this study was to develop a landfill suitability map for Alwar City based on its 2051 master plan boundary. The uniqueness of this research stems from the combination of geospatial technology and MCDA to tackle the issue of identifying suitable landfill sites. This challenge has been largely overlooked in Indian cities. This study integrates environmental factors, such as forest area, to take ecological consideration of the Aravalli range, groundwater, etc. Socioeconomic factors include roads and residential areas. This research holds considerable significance, as it adds to the existing knowledge on selecting landfill sites that are scientifically sound, socially acceptable, and economically feasible in a densely populated and agrarian nation such as India. It will address waste management challenges, such as air, water, soil pollution, and public health, aligning with the principle of sustainable development goals 6 and target 6.3 by 2030 (The Sustainable Development Goals Report, 2024).

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Description of Study Area

Alwar, a city steeped in rich historical significance, is situated in the northern Indian state of Rajasthan (Figure 1) at a latitude of 27.5530° N and longitude of 76.6346° E, with an average elevation of approximately 268 m (879 feet) above sea level (Aquifer and Groundwater Mapping of Alwar, 2013). Nestled within the Aravalli Range in northeastern Rajasthan, the Alwar is characterized by rugged terrain surrounded by hills and forests. The region experiences a semi-arid climate, which is classified under the Köppen climate classification system as Cwg. The monsoon season, which begins in late June and continues until September, brings moderate to heavy rainfall, averaging approximately 600 mm annually (Aquifer and Groundwater Mapping of Alwar, 2013). According to the 2011 Census, Alwar City has a population of approximately 341,422 residents (Directorate of Census Operations, Rajasthan, 2011). As the city expanded, new areas emerged, featuring broader roads, modern residential complexes, and commercial spaces. This rapid urbanization has resulted in mixed land-use patterns, where residential, commercial, and industrial activities often coexist (Factsheet of Industrial Emissions, 2023). Furthermore, Alwar's proximity to Delhi and Jaipur has played a significant role in its growth as part of the National Capital Region (NCR), shaping its economic and spatial development trajectory.

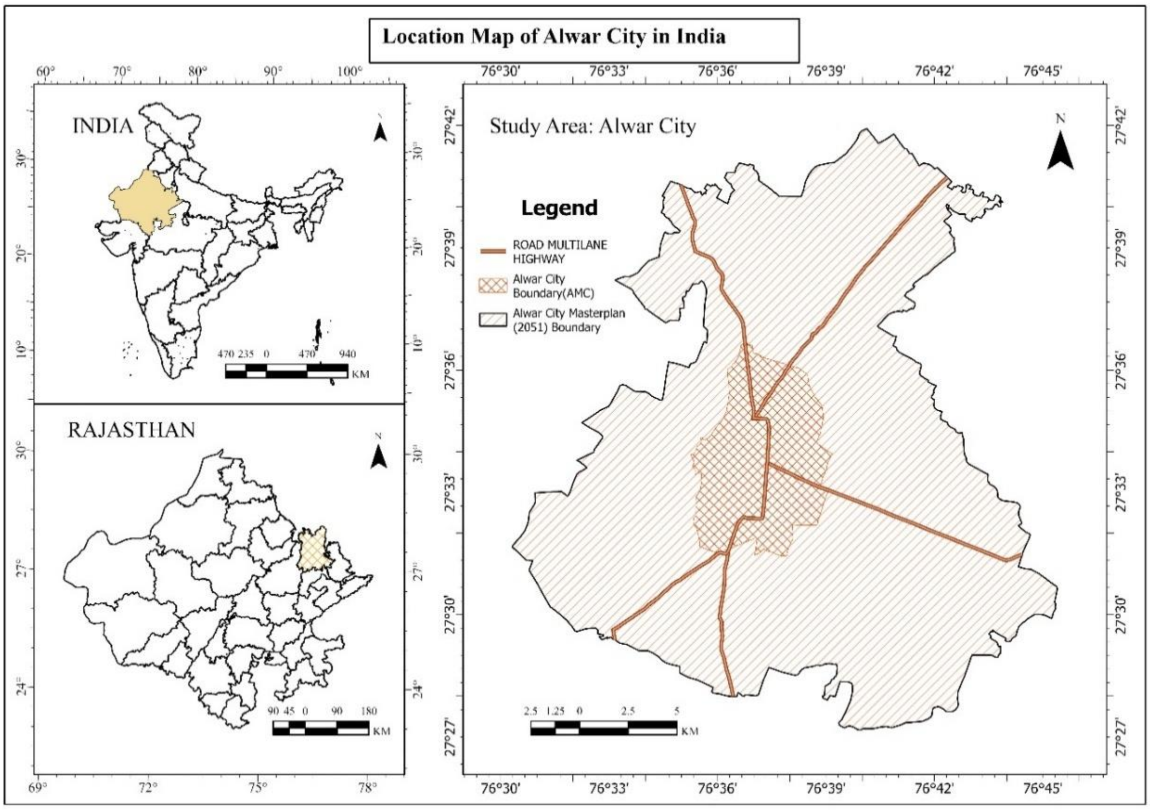

***Figure 1**. Location of Alwar City in India*

Material and Methods

Data Collection

This study contains ten distinct input map layers: elevation, slope, residential area, roads (highways), aquifers, rivers, land use and land cover, forest area, soil texture, and water body (Table 1). The constraint criteria are identified based on the existing rules of the CPCB, RSPCB, and Municipal Solid Waste Management Rule 2016 and from academic experts of relevant disciplines to safeguard the environment, public health, and other aesthetic aspects. The constraint criteria are a water body and a 500m area around it, a river and a 500m area around it, a residential area and zone of 400m and a dense and moderately protected forest area. Factors such as water bodies, rivers, residential areas, and forests are both factor criteria, and constraint criteria are double criteria.

Data for LULC and Water Body layer sourced as Sentinel 2A Imagery for 2023 with 10m resolution obtained from the European Space Agency, roads data from Open Street maps plate form, other data such as river, aquifer, soil, sourced from India WRIS Portal Government of India, while Digital Elevation data sourced from SRTM 30M resolution, USGS Earth Explorer. All map layers were created using ArcGIS software, with statistical analysis of MCDA AHP conducted through Microsoft Excel 2021. Each map layer adheres to a unified reference system consistent with national mapping standards, specifically WGS 84 and UTM 43N. A raster data model was selected, and every input map layer, whether initially in

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raster or vector format, was either resampled or converted to a raster with a consistent grid size of 30 meters. The layers, buffer zones, and rankings are below (Table 1).

***Table 1**. Summery of input data used in this study*

Layer name	Source map	Buffer zones(m)	Ranking
Residential Area	Sentinel 2A 2023 imagery. Supervised classification of LULC.	0-200	1
		200-400	1
		400-800	3
		800-1200	4
		>1200	5
Distance from Roads	open street map portal	0-200	1
		200-400	2
		400-800	3
		800-1200	5
		>1200	4
Distance from River	Hydrological data India WRIS	0-200	1
		200-400	2
		400-800	3
		800-1200	4
		>1200	5
Groundwater Aquifer	India WRIS, GSI vector data	Gneiss and Quartzite	5
		limestone	1
		marble	2
		schist	3
		older alluvium	4
Soil Texture	India WRIS portal Spatial data (rater file)	fine texture	3
		coarse texture	2
		rocky and non-soil	4
Forest Area	Forest Survey of India raster data	water body	1
		dense forest	2
		moderate dense	3
		open/scrub vegetation	4
		non forest	5
LULC	Sentinel 2A 2023 imagery. Supervised classification of LULC.	water	1
		built-up	2
		agriculture	3
		vegetation	4
		barren land	5
Slope (in Degree)	USGS Earth Explorer, SRTM 30M	0-12	5
		12-25	4
		25-38	2
		38-51	1
		51-63	1
Elevation	USGS Earth Explorer, SRTM 30M	229-272	1
		272-322	2
		322-401	3
		401-489	4
		489-602	5
Water Body	LULC Classification	0-500	1
		>500	5

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Methods

Setting of Factor Criteria

The criteria are broadly categorized into environmental factors (river, soil, forest, aquifers, water body elevation and slope) and socio-economic factors (roads, residential area, land use, and land cover). All factor criteria are ranked from 1 to 5: one is not suitable, two is less suitable, three is moderately suitable, four is suitable, and five is most suitable (Table 1).

River and Streams. A safe distance from water bodies like rivers, ponds, etc., is crucial because landfills generate leachate and unpleasant gaseous emissions that can contaminate groundwater (Rezaeisabzevar et al., 2020). This study's river and stream criteria are <200 m unsuitable, 200 – 400 m less suitable, 400-800 m moderately suitable, 800-1200 m suitable, and >1200 m most suitable.

Land Use and Land Cover (LULC). Land use and land cover (LULC) are crucial considerations when selecting locations for landfill sites to mitigate environmental harm (Gorsevski et al., 2012). The 2023 Sentinel 2A Satellite Imagery underwent a supervised classification process with ArcGIS software, employing the maximum likelihood parametric decision rule (Saini et al., 2024). This classification relied on a predetermined LULC classification scheme from ESRI and a field survey of the study area. The framework encompassed six categories: water bodies, vegetation, built-up areas, agriculture, wasteland, and bare land. The relative suitability of different land use classes is shown in Table (1).

Roads. The ease of access and year-round usability of the road are crucial factors for landfill site suitability. It is essential to position a landfill at a reasonable distance from both primary and secondary roads (Kontos et al., 2005). Based on various literature, this study uses different buffer distances: <200 m unsuitable, 200 – 400 m as suitable, 400-800 m as most suitable, 800-1200 m as moderately suitable, and >1200 m less suitable.

Residential Area. The safe distance between the residential area and the landfill site is one of the several factors that need to be taken into account, as the optimum distance will keep the transport cost of waste to the dumping site low and reduce the adverse effect of the landfill site at the same time (Alkaradaghi et al., 2019; Jamshidi et al., 2015). Based on these considerations, the buffer distance from the residential area is as follows: <200 m is unsuitable, 200 – 400 m is less suitable, 400-800 m is moderately suitable, 800-1200 m is suitable, and >1200 m is most suitable.

Elevation. Elevation is vital in landfill site selection, influencing drainage, accessibility, and potential environmental impacts (El Baba et al., 2015). The role of elevation varies according to local conditions; the study area is situated in the hill area of Aravalli; thus, elevation is relevant in this study. The elevation in this region varies from 229 to 602 meters. To safeguard the environment and biodiversity and to avoid mountainous regions, elevations between 229 and 272 m are most suitable, 272 to 322 m are suitable, 322 to 401 m are moderately suitable, 401 to 489 m are less suitable, and elevations above 489 meters as not suitable.

Slope. The slope is an important factor in minimizing landscaping costs and leachate leakage; gentle slopes are most suitable for landfills (Demesouka et al., 2014). A steeper slope is unsuitable due to the higher cost of construction and maintenance of landfill sites (Alanbari et al., 2014). In the study area, slope values range from 2◦ to 63◦, slopes between 0◦ and 12◦ are considered most suitable, 12◦ to 25◦ are suitable, 25◦ to 38◦ are moderately suitable, and those greater than 38◦ are not suitable.

Aquifer. Aquifers are the critical factors in landfill site selection due to the potential risk of groundwater contamination (Kharat et al., 2016; Pasalari et al., 2019). The aquifer in the study area has five types; based on existing literature, the relative suitability is assigned as Gneiss and Quartzite are most suitable, limestone is considered unsuitable, marble is suitable, schist is moderately suitable, and older alluvium is less suitable.

Soil. Soil texture, defined by the proportions of clay, sand, and silt particles, is key in determining landfill site suitability, as clayey soils are generally preferred for landfills due to their low permeability, which helps prevent leachate from contaminating groundwater (Elkhrachy et al., 2023; Kapilan & Elangovan, 2018). Three distinct soil types were identified in the study area: fine-textured soil, deemed moderately important; coarse-textured soil, considered less suitable; and rocky or nonsoil types, regarded as suitable.

Forest. Forests are sensitive and ecologically fragile areas important for selecting landfill sites. Forested areas should considered less suitable for landfill site selection (Kharat et al., 2016). The study area is situated on the outskirts of the Aravalli Mountain range, where various types of forests and vegetation are present. For landfill suitability, the non-forest areas are most suitable, open or scrub forest areas are considered suitable, moderately dense forests are seen as moderately suitable, and dense forest areas are unsuitable.

Water Body. Protecting water resources is a primary concern in landfill site selection. Maintaining adequate distance from surface water bodies is crucial to prevent contamination (Vasanthi et al., 2008). The proximity to water bodies is an important constraint, as landfills located too close can lead to water pollution and contamination (Ashraf et al., 2013; Vasanthi et al., 2008). In this study, a safe distance of 500 m is considered unsuitable, but beyond that, it is considered suitable.

Multi-Criteria Decision Analysis

Multi-criteria decision analysis (MCDA) is a systematic method used to assess and prioritize options based on several, often competing, criteria. This method is becoming popular in various domains, such as environmental impact evaluation, healthcare decision-making, and conservation management (Bojórquez-Tapia et al., 2005; Davies et al., 2013). Various MCDA techniques are employed for decision-making tasks, such as determining the suitability of landfill sites. This research utilizes the Analytical Hierarchy Process (AHP) and Weighted Linear Combination (WLC) methods of MCDA. Microsoft Excel 2021 is utilized to create the pairwise comparison matrix.

Analytic Hierarchy Process.

AHP was developed by Satty in 1980 and is based on pairwise comparison to determine the relative importance of the criteria (Saaty, 1980). It facilitates the prioritization of criteria and supports complex decision-making by deconstructing criteria into hierarchical structures with quantitative and qualitative elements (McIntyre & Parfitt, 1998). This method successfully selects wastewater treatment processes (Karimi et al., 2011). In this study, focus group discussion was conducted with expert professors from various disciplines such as geology, geography, hydrology civ, civil engineering and experts in public administration to assign the relative importance of Satty's nine-point scale (Mvula et al., 2023). The relative importance of ten criteria, as in Table (2), is assigned in a pairwise comparison matrix. This method involves comparing alternatives or criteria in pairs to determine their relative importance or preference (Csató, 2017; Mohd & Abdullah, 2017; Zhou et al., 2018).

According to Saaty and Vargas in (Saaty & Vargas, 2012), the consistency ratio (CR) for pairwise comparisons should be below 10%. The Consistency Index (CI) was calculated using the following formula:

$$CI = \frac{\lambda max - n}{(n-1)} \quad (1)$$

In this context, whereas n denotes the total number of criteria, λmax is the largest eigenvalue of the judgment matrix. A lower Consistency Index (CI) indicates greater consistency in the pairwise comparison matrix. The Consistency Ratio (CR) is determined by dividing the CI by the Random Consistency Index (RI) for the given value of n, as illustrated in Table 3.

$$CR = \frac{CI}{RI} < 0.1 \quad (2)$$

Table 2. *Random Index Value*

Order Matrix (n)	1	2	3	4	5	6	7	8	9	10
Random Index (RI)	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

Source: Satty(1980)

WEIGHTED LINEAR COMBINATION (WLC).

This method is the most commonly used decision-making technique in GIS for creating composite. It allows the integration of various factors, with specific weight based on their relative importance, to derive a final suitability or vulnerability map (Malczewski, 2000; Mvula et al., 2023; Vavatsikos et al., 2020). In this study, the result from AHP was combined with WLC to get the final suitability map (Mvula et al., 2023). WLC is used to aggregate criteria weights and develop the suitability index value of potential area using the formula:

$$s_i = \sum_{J=1}^{n} w_{i*} x_{ij} * \Pi c_j \quad (3)$$

In this context, Si denotes the suitability index for area i, and wi denotes the criterion's weight. Xij is the value of the criterion, with n being the total number of criteria and Cj indicating the constraint score, which can be either 0 or 1 (Gorsevski et al., 2012; Rezaeisabzevar et al., 2020). All ten map layers were standardized using ArcGIS, where each layer was "reclassified" through the spatial analyst tool. Each class was assigned a rank from 1 to 5, with one indicating not suitable, two less suitable, three moderately suitable, four suitable, and five most suitable.

Result and Discussion

Suitability Condition of Factor Criteria

The total area for landfill suitability is ranked 1 to 5, where 1 indicates the least suitability and 5 represents the highest suitability, with 2, 3, and 4 denoting less suitable, moderately suitable, and suitable, respectively. Figures 2 and 3 illustrate the spatial distribution of suitability classifications based on factor criteria. The factors criteria, such as rivers and streams, show that around 98% of the area falls under the most suitable category because the study area lacks perennial streams. Similarly, a water body 2% area is classified as not suitable as a constraint area around 500m of a water body to prevent leachate leakage and contamination of the water body (Asfaw et al., 2024). This data also explains that the study area is in arid condition, has no primary water source, and largely depends on groundwater for water supply.

Meanwhile, aquifer factor criteria are around 9% under the most suitable category, and 81% are classified as suitable. Similarly, 66% classified the most suitable and 10% as suitable under the road (highways) criteria. While residential areas are a significant constraint for landfill suitability, 73% are classified as not suitable, 9% as suitable, and 11% as most suitable due to rapid urbanization and infrastructure development in the study area. In land use and land cover factor criteria, 1% of the area is most suitable as barren land and sparsely vegetated, while 53% of the area is moderately suitable due to agricultural land; this is the fact that the study area is primarily agriculture dependent. Regarding slope and elevation criteria, 64% were classified as most suitable and 19% as suitable because the western part of the study area is covered under the mountain range of the Aravalli mountains. Similarly, of the Forest areas that occupy the western and northern part of the study area, 20% are classified as unsuitable and the rest, 80%, as suitable.

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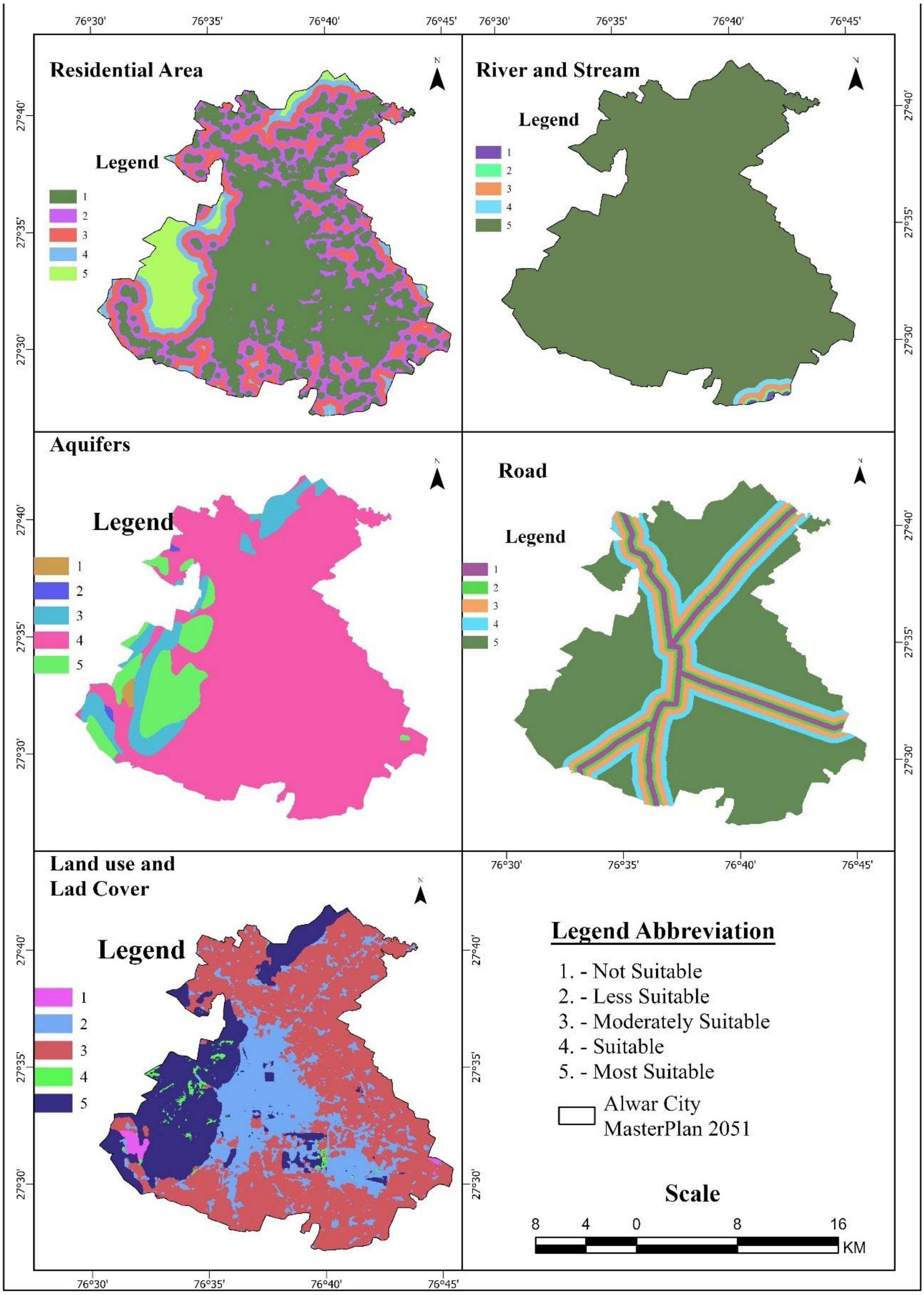

Figure 2. *Factor Criteria Maps Continue-*

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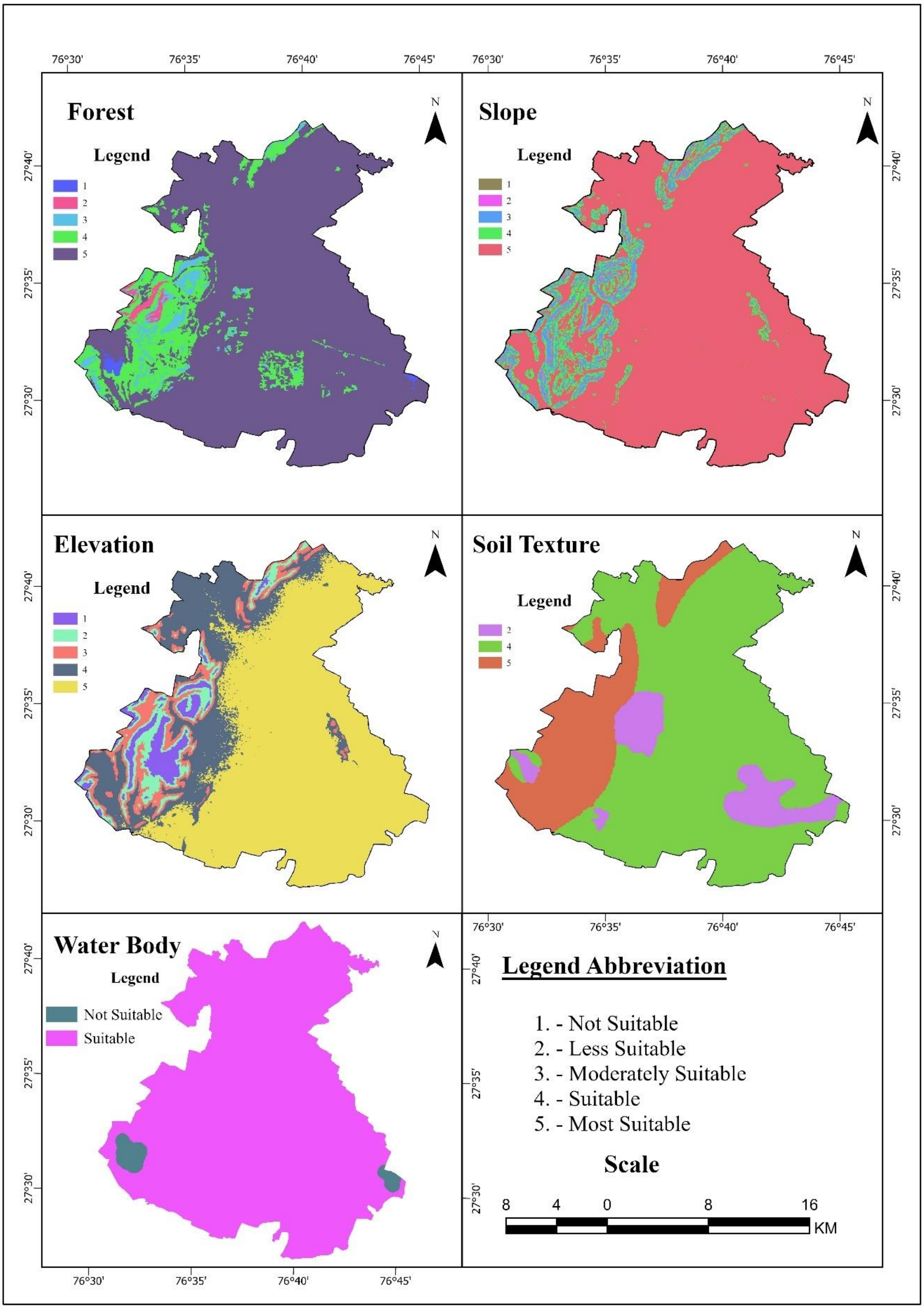

Figure 3. *Factor Criteria Maps*

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Table 3. *Pairwise Comparision matrix*

	RA	RO	RI	AQ	ST	FA	LU	S	E	WB	EVW	Percentage Weight
RA	1	3	1	4	7	1	5	5	7	1	0.189	**18.9%**
RO	1/3	1	1/3	1	5	1	2	3	5	1/3	0.089	**8.9%**
RI	1	3	1	3	5	1/3	3	5	5	1	0.155	**15.5%**
AQ	1/4	1	1/3	1	3	1/3	1	3	5	1/5	0.066	**6.6%**
ST	1/7	1/5	1/5	1/3	1	1/5	1/3	1/3	1	1/7	0.022	**2.2%**
FA	1	1	3	3	5	1	1	3	5	1/3	0.142	**14.2%**
LU	1/5	1/2	1/3	1	3	1	1	2	3	1/5	0.061	**6.1%**
S	1/5	1/3	1/5	1/3	3	1/3	1/2	1	2	1/5	0.038	**3.8%**
E	1/7	1/5	1/5	1/5	1	1/5	1/3	1/2	1	1/7	0.022	**2.2%**
WB	1	3	1	5	7	3	5	5	7	1	0.218	**21.8%**
Total	**5.27**	**13.23**	**7.60**	**18.87**	**40.00**	**8.40**	**19.17**	**27.83**	**41.00**	**4.55**	**1.00**	**100.00**
RA=Residential Area, RO=Road, RI=River, AQ=Aquifer, ST=Soil Texture, FA= Forest Area, LU=LULC, S=Slope, EL=Elevation, WB=Water Body, EVW=Eigen Vector Weight												
Lambda = 10.764, CI= 0.0849, CR= 0.056 or 5.6%												

Constraint Map

The constraint map, as shown in Figure 4, is generated from criteria that are identified based on existing rules of CPCB, RSPCB, and Municipal Solid Waste Management Rule 2016, as well as from academic experts of relevant discipline to safeguard the environment, public health and other aesthetics aspect. The constraint factors are a water body and a 500m area around it, a river and a 500m area around it, a residential area and zone of 400m and a dense and moderately protected forest area. After combining all constraint areas, the result is that around 89% of the area is not suitable for landfill site suitability, and only 11% of the area is suitable. This study reveals that the west and north parts of the city are covered with hills and forest areas, and the north and the eastern parts are primarily residential and built-up areas that are mostly restricted to landfills. This research focused on safeguarding, restoring, and promoting the sustainable utilization of land ecosystems by effectively managing forests and stopping and reversing land degradation. Once the study's findings are implemented, they will support the advancement of sustainable cities and communities (SDG 11) (The Sustainable Development Goals Report, 2024). By ensuring that urban areas and human communities are secure, adaptable, and sustainable, we can ultimately achieve the objective of SDG 3, which focuses on enhancing health and well-being through the prevention and treatment of infectious diseases and pandemics (The Sustainable Development Goals Report, 2024).

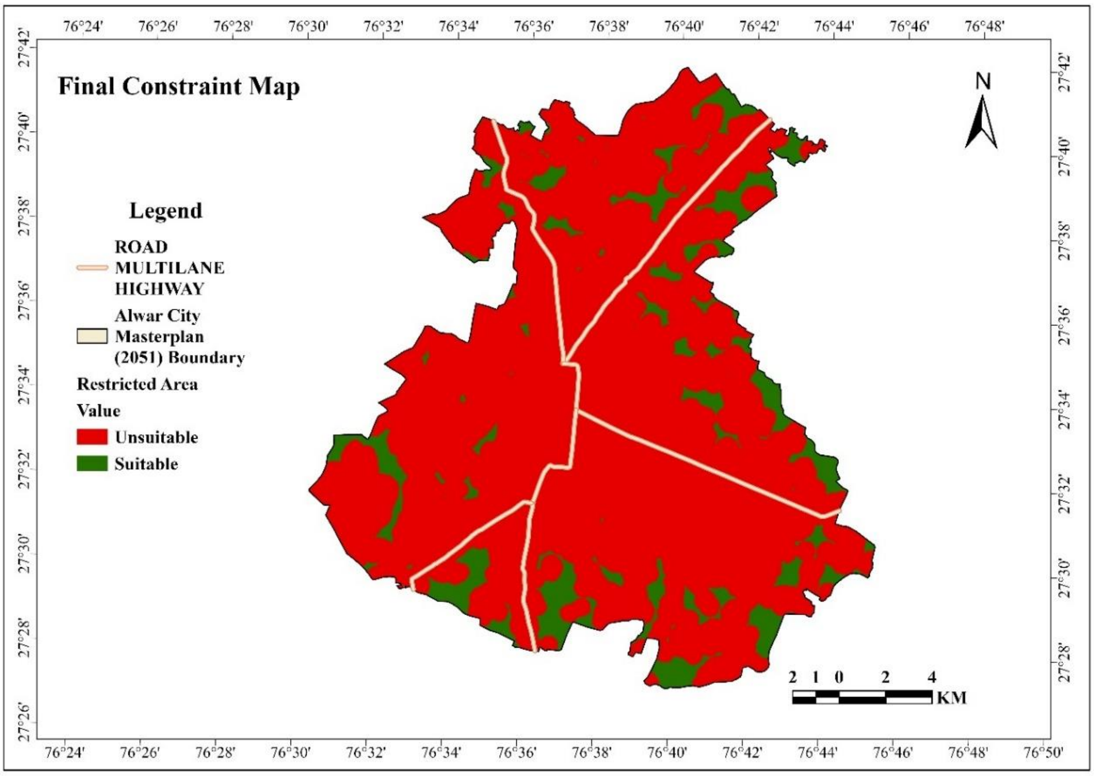

Figure 4. *Final constraint map of Study area*

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Landfill Suitability

The final landfill suitability map was created using Eq. (3), incorporating the MCDA and AHP pairwise comparison matrix results from Table 3. The findings indicate that less than 8% of the area is suitable for landfill, while 89% is designated as restricted, and 3% is deemed moderately suitable.

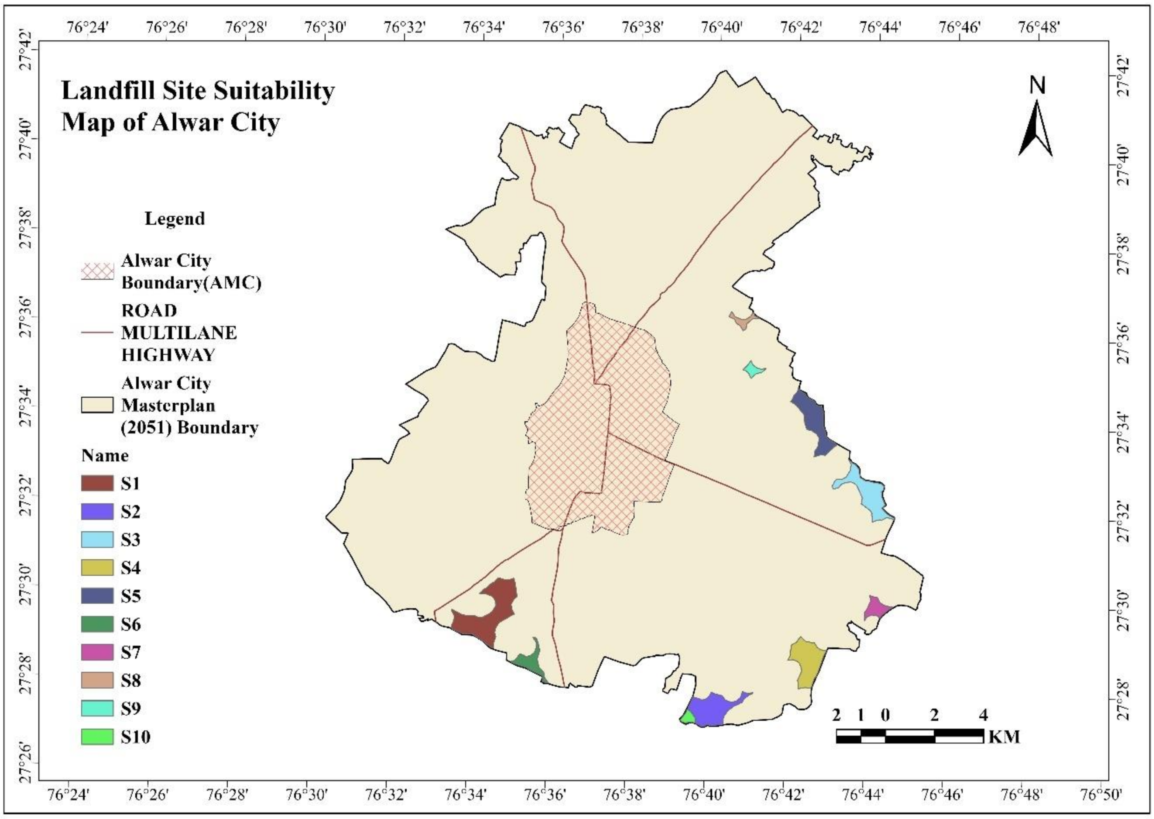

Figure 5. *Final Landfill Site Suitability Map*

The final landfill suitability map was created using Eq. (3), incorporating the MCDA and AHP pairwise comparison matrix results from Table 3. The findings indicate that less than 8% of the area is suitable for landfill, while 89% is designated as restricted, and 3% is deemed moderately suitable. According to the city's master plan for 2051, most plans are in the north and eastern parts, and establishing an education zone is in the city's southwest. At the same time, the city is currently generating around 160 tons of waste per day, while the population growth of the city is 2.1- 2.2% annually, taking into account a minimum of 20 hectares of land required, while the most suitable would be above 50 hectares in area, taking future needs into account. While superimposing the required criteria, 10 suitable sites are identified, i.e., S1, S2, S3, S4, S5, S6, S7, S8, S9, and S10, as shown in Figure 5; these sites meet the minimum criteria, site S1 to S7 are most suitable as the area is above 50 hectares, while S3 is near existing landfill site located in 15 hectares of land area. The existing landfill site was selected a decade ago, and the region has now transformed into an industrial hub and is densely populated. Thus, this study not only promotes clean and sustainable waste disposal sites but also takes future considerations for waste disposal.

Conclusion and Recommendation

The landfill site suitability map for Alwar City Municipal Corporation is produced using the Geographic Information System (GIS), Multi-Criteria Decision Analysis (MCDA) and Analytical Hierarchy Process (AHP). GIS, MCDA and AHP considered environmental factors (river, soil, forest, aquifers, water body elevation and slope) and socio-economic factors (roads, residential area, land use, and land cover) for finding the most suitable landfill sites. The most suitable sites are located in the eastern and south-eastern parts of the study area, such as S2, S3, S4, S5, S7, etc., and out of the most suitable for the years 2051, S2, S3, S4, and S5. The two sites can be considered from the eastern parts S3 and S5 and the eastern parts S2 and S4 to reduce transportation costs. This research demonstrates the practicality of integrating a multi-disciplinary approach with scientific methods. This integration results in minimal environmental, economic, and public health concerns, a critical issue in developing nations like India. The study approach also aligns with the core objectives of Sustainable Development Goals 11 and 6. It highlights the importance of protecting our environment and public health to achieve sustainable cities and communities, as well as clean water and sanitation.

This study is significant as it enhances the current understanding of selecting appropriate landfill sites in developing countries. Landfill sites should be scientifically selected and accepted by the community. We recommend that local governments enhance their capabilities and infrastructure facilities and integrate GIS and MCDA methods for waste management. This approach helps in more environmentally sustainable, economically viable and socially acceptable landfill selection and utilization.

Statements and Declarations
Declaration of competing interests
The authors declare that they have no financial interests or personal connections that might have influenced the findings presented in this paper.
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