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An Integrated GIS-AHP Approach for Municipal Solid Waste Landfill Siting in Srikakulam District, Andhra Pradesh

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ABSTRACT

The availability of land for proper waste disposal is one of the most important and emerging potential challenges in most big cities. Although some attempts are being made to minimize and recover garbage, landfill disposal continues to be the dominant method of waste disposal. An improper landfill site can negatively impact the environment, the economy, and the environment. Thus, it should be carefully chosen, taking into consideration both rules and standards from other sources. To examine all aspects of this study, an integration of the "Geographic Information System (GIS)" and the "Analytic Hierarchy Process (AHP)" was incorporated for land-fill site selection. Various parameters were examined to make decisions about landfill site selection. These parameters included slope, elevation, soil texture, LULC, surface water, groundwater table, road network, historical areas, and residential areas. An analytic-hierarchy process was used to determine the relative importance of each parameter, and a final site suitability map was created. With an equal interval classification method, the final index model was categorized into four categories, which included "unsuitable", "less suitable", "moderately suitable" and "suitable". As a result, 30.28% of the study area was less suitable, 28.49% was moderately suitable, 12.39% was suitable, and 28.84% of the study area was unsuitable for landfilling.

INTRODUCTION

The current environmental concerns have stimulated the interest of institutions, industries, and the general public in two critical concepts: sustainability and circular economy (Ingrassia et al. 2020, 2019). A circular economy-based production would allow us to meet current needs without compromising the ability of future generations to meet their own needs by optimizing resources, energy consumption, wastes, and emissions through protracted design, maintenance, and 5R(repair, reuse, remanufacturing, refurbishing, and recycling). This is in contrast to linear economies based on a "make-use-dispose" model of resource consumption (Ingrassia et al. 2020, Penki & Rout 2021, Silva de Souza Lima Cano et al. 2022). Many of them believe that sustainability is associated with environmentalism, but it is based on three pillars: economy, social, and environmental sustainability.

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Solid waste management (SWM) has attracted new attention due to the urgent requirement to adhere to the circular economy (CE) principles and improve waste management rather than disposing of waste in landfills or dumping it in the environment (Silva de Souza Lima Cano et al. 2022). As a means of achieving CE, it is necessary to devise strategies for recovering and preserving the waste generated at all stages of both the production and consumption value chains, whether it is man-made materials, natural resources, or manufactured materials, components, and goods (Geneletti 2010, Ingrassia et al. 2020). This refers to the recovery of resources from the garbage. The recovery of resources from garbage is not an easy task. It is dependent on the different compositions of solid waste and the various collections and management schemes used across the world (Kamdar et al. 2019, Nas et al. 2010, Penki & Rout, 2021). On the other hand, recovering resources from garbage is a difficult process; garbage must be disposed of efficiently and scientifically while safeguarding health and the environment. Perhaps, the construction of landfill sites for multiple purposes provides a clear perspective for resource recovery and contributes value in the real world. However, getting this done by a manual survey is a very big task that involves much manpower and time. So, within this approach, the application of RS and GIS is attracting significant interest in environmental considerations for sustainable municipal solid waste(MSW) site selection (Balew et al. 2022, Ingrassia et al. 2019, Şener et al. 2010).

Land-fill site selection is a significant and complicated phase that is influenced by various factors and laws. Further research is needed to consider numerous morphological, economic, and environmental elements that to provide the optimal location with the lowest socioeconomic and environmental costs (Al-Anbari et al. 2014, Barakat et al. 2017). A wide range of analyses have been conducted on urban landfill sites throughout the major regions of the world, and many criteria, such as morphological, economic, and environmental, have been employed to choose sites (Al-Anbari et al. 2014, Barakat et al. 2017, Sumathi et al. 2008). Environmental considerations are crucial, knowing that the landfill might have an impact on the bio-physical environment and the biological system of the neighboring areas (Barakat et al. 2017, Eskandari et al. 2016, Pasalari et al. 2019, Torabi-Kaveh et al. 2016). Land-fill Siting Suitability assessment is complex because of the multiple and various (morphological, economical, and environmental) criteria since it is difficult to integrate them and give them weights(Barakat et al. 2017). GIS-based multicriteria evaluation (MCE) is therefore an ideal tool for such analyses since it can handle a huge amount of spatial data from diverse sources (Barakat et al. 2017, Rahmat et al. 2017, Wang et al. 2009). Since GIS can handle enormous amounts of geographical data from diverse sources, GIS-based multicriteria evaluation (MCE) is an appropriate tool for such evaluations (Ahire et al. 2022, Al-Anbari et al. 2014, Barakat et al. 2017, Bosompem et al. 2016, Feo & Gisi 2014, Ravinder & Ramu 2020, Sumathi et al. 2008). GIS-based multicriteria suitability assessment is one of the most successful assessment strategies for generating models for garbage landfill sites because of their capacity to handle a vast level of spatial data from a range of sources (Barakat et al. 2017, Kamdar et al. 2019, Pasalari et al. 2019, Rao & Babu 2018, Silva de Souza Lima Cano et al. 2022). One of the challenges in the MCE process is evaluating the weight of selected criteria that have unequally influenced land suitability (Barakat et al. 2017). While there are numerous ways to determine the weighting of these factors, the analytical hierarchy process (AHP) has typically been used strategy (Bahrani et al. 2016, Barakat et al. 2017, Donevska et al. 2011, Geneletti 2010, Moeinaddini et al. 2010, Nas et al. 2010, Penki et al. 2022a, 2022b, Rahmat et al. 2017, Ramu 2020, Şener et al. 2010, Sumathi et al. 2008, Torabi-Kaveh et al. 2016, Wang et al. 2009).

To develop appropriate land-fill sites for the Srikakulam district, the present research used AHP and GIS techniques to develop a final suitability map. The spatial analysis was

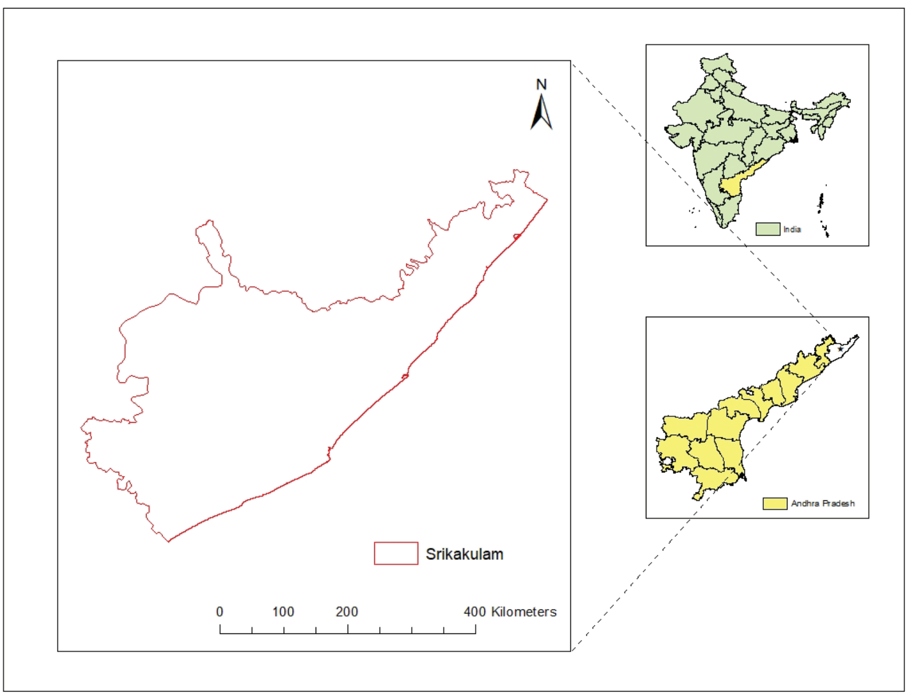

Fig. 1: Study area map.

conducted using AHP methods within a GIS environment, using quantifiable data.

STUDY AREA

Srikakulam District is the extreme Northern District of Andhra Pradesh within the geographic coordinates of 18° 20’ and 19° 10’ of Northern latitude and 83° 50’ and 84° 50’ of Eastern longitude. It has a total area of 5,837 sq km with a total population of 2,703,114. The key features of Srikakulam are it has about 1865 revenue villages, a coast-line of 193 km, and a rail network of 128 km. Urbanization in conjunction with lifestyle change contributes to higher waste generation (Fig. 1). As per CPCB, only 68% of the MSW generated in the country is collected of which, 28% is treated by the municipal authorities. The research area is mostly surrounded by residential areas, agricultural areas, scrublands, and quarry sites. The generation of solid waste is expected to rise as a product of fast urbanization, migration of people, and an improvement in people’s standard of life. This requires proper waste treatment and disposal; otherwise, unsanitary scenarios arise. However, new landfill sites are required to meet future requirements and to dispose of the waste scientifically. As a result, the study for this research focuses on GIS and AHP for landfill location selection.

MATERIALS AND METHODS

The first stage in solid waste disposal by landfill is to pick the relevant site. The selection of a landfill site involves consideration of various morphological, environmental, and socio-economic cost aspects, as well as obeying governmental regulations. The landfill location for Srikakulam is being identified by employing GIS and AHP in the present research. To begin, the criteria for selecting the landfill are divided into three categories: morphological, environmental, and socio-economical characteristics (Fig. 2). Morphological factors such as slope, elevation, and soil texture are taken into account for evaluating appropriateness. Similarly, under the environmental criteria, land use, land cover, surface water, and groundwater table are taken into account. From the socio-economic viewpoint, the distance of various sites from roadways, the distance of various historical landmarks, and the distance from residential areas are all taken into account for evaluating suitability. A thematic map is created using GIS for each criterion. The AHP approach is used to compute rankings for each criterion. The produced thematic maps are reclassified using the previously acquired rankings for overlay analysis. The overlay analysis is used to produce the Land Suitability Index (LSI) for the study area. The research region is divided into four groups based on the acquired LSI values: unsuitable, less suitable, moderately suitable, and suitable.

Data-Collection

The purpose of this research was to identify viable areas for “Municipal Solid Waste(MSW) disposal”. The most recent data was acquired from multiple web portals. The elevation and slope maps were generated using SRTM-Dem, which was acquired from USGS Earth Explorer. The FAO/UNESCO Soil Map of the World is used to acquire data on soil texture. The LULC map was created using Landsat-8 imagery. The Global surface water explorer provided the surface water. The data for the groundwater table was

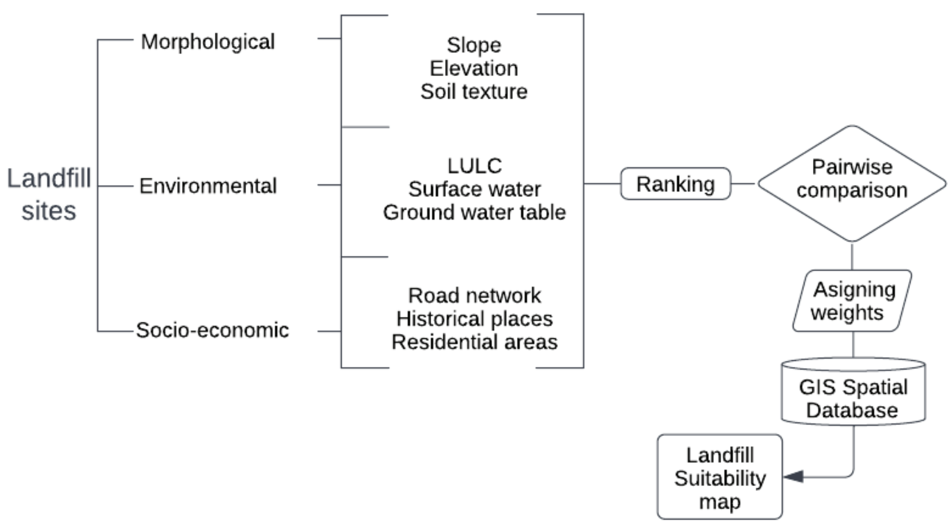

Fig. 2: Flowchart of the methodology.

collected from the India WRIS. The road network data was retrieved from Diva-Gis, and the locations of historical sites and residential areas were determined by hand.

Morphological Perspective

Slope and Elevation

Slope and elevation are the two most important criteria to consider while constructing a landfill site. Highly sloping terrain demands costly operating processes that are not cost-effective making it the least desired option. In addition, very elevated places are not suggestible. Land slopes ranging from 0° to 10° have been proposed as suitable for landfill site building As a result, locations with slopes larger than 15° were deemed inappropriate, but those with only a small slope of less than 5° were deemed quite acceptable. Similarly, elevations over 120 m were deemed undesirable, but elevations below 40 m were deemed quite acceptable in this study. Using data from the USGS earth explorer, a DEM (digital elevation model) of the research region was created. ArcGIS software was used to create the slope and elevation maps.

Soil-Texture

"Soil" has a considerable impact on the quantity of groundwater that penetrates the earth and, as a consequence, on the number of contaminants that are capable of flowing into the unsaturated zone (Kamdar et al. 2019). Clay and silt are made up of smaller particles that can reduce the permeability of the soil and limit contaminant penetration. Sand and sandy loam are among the most permeable soils and are thus inappropriate for landfills, However, clay and clay loam are among the least permeable soil types, while sandy clay is acceptable. The water permeability and high porosity of sandy soil can cause landfill sites to impact water quality, which can lead to landfill sites releasing contaminants into the water. Thus, a soil texture map was generated for the research region using the FAO/UNESCO global soil map, and three soil type layers were discovered, with loam, sandy clay loam, and sandy loam graded as very-appropriate, moderately-suitable, and not-suitable, respectively.

Environmental Perspective

LULC

Land usage depicts how humans interact with the land and the natural environment. Forest, agricultural, residential, industrial, military, and archaeological regions, water bodies, and bare and wet terrain are all examples of land-use types. However, distinct barren, vegetated, and agricultural lands are the best places for landfill construction. This criterion's goal is to conserve highly productive or undeveloped areas while still ensuring minimal capital costs. Thus, forests and residential areas were deemed unsuitable for dump sites, and historical regions were also deemed undesirable. Industrial areas, which play an essential part in the growth of an area, were graded as moderately-sensible, whereas barren, vegetated, and agricultural lands were considered extremely suitable. Finally, the most highly desirable locations designated for landfill sites in this study were barren lands.

Surface Water

Landfills emit toxic gases and effluent. As a result, landfills must not be built near bodies of water such as streams, lakes, ponds, & rivers. According to the Central Pollution Control Board (CPCB) Central Public Health & Environmental Engineering Organisation (CPHEEO), Govt of India, for wetlands and any other water body, a buffer zone of 300 m is recommended. Therefore, a buffer zone of 300 m was validated for all surface waters, and any area with a buffer zone of fewer than 300 m from surface water was deemed unsuitable, while buffer zones of 300 m to 600 m and 600 m to 900 m, respectively, were deemed moderately-suitable, and buffer zones greater than 900 m were deemed highly-suitable.

Groundwater Table

According to the CPHEEO and CPCB, a landfill site should be located in an area with a suitably low groundwater level, while sites with an immense groundwater intensity require a specific layout. In this work, the depth of the groundwater table was determined using an inverse distance weighting (IDW) interpolation technique to water level data. Groundwater depths of "0-1.5 m", "1.5-3 m", and "3-4.5 m" were found to be inappropriate, moderately suitable, and extremely suitable, respectively. Depths of more than 4.5 m were confirmed to be appropriate.

Socio-Economic Perspective

Road Network

Another key economic consideration that influences dump site location selection is the distance from roadways. Since landfills are expensive to transport, they shouldn't be positioned too far away from roads; as their distance from roads increases, their suitability ranking decreases (Kamdar et al. 2019). As a result, a permanent road connecting the waste site to the active road network is required. For minor operations, the roadway ought to be 5m wide, and for bigger dumps, it must be 6 to 8 m wide. Furthermore, garbage trucks should not obstruct traffic movement. In this study, a distance of greater than 1000 m from a road network is

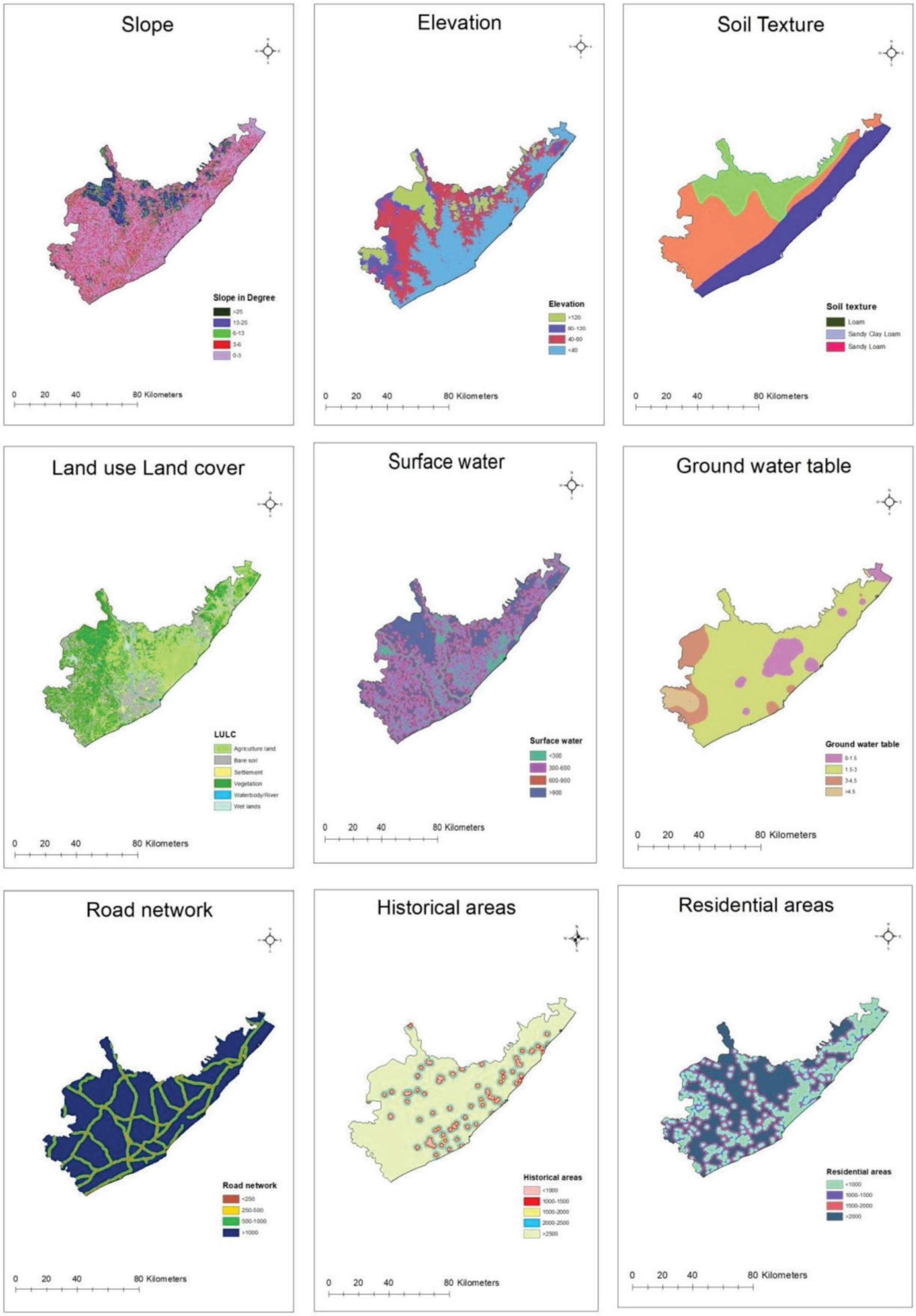

Fig. 3: Maps illustrating the suitability of evaluated criteria for Municipal solid waste landfill siting.

deemed extremely suitable for vehicles, while distances of lesser than 250 m are deemed unsuitable by the Department of Highways.

Historical Places

Temples, parks, restaurants, hotels, theatres, commercial malls, and waterfalls are among the historical landmarks in the studied region. According to the CPHEEO and CPCB, construction of landfill sites within 1000 m of historical sites is forbidden. As a result, based on GIS software data, a buffer zone of 1000 m was established near "historical sites." In this study, a buffer zone of less than 1000 m was deemed undesirable, whereas one of more than 2500 m was deemed extremely appropriate.

Residential Areas

According to the "Not In My Backyard (NIMBY)" phenomenon, this criterion is extremely essential and is the primary feature accountable for minimizing the count of appropriate sites for landfills. The vicinity of a landfill to a household area addresses a series of environmental issues, including pricing, future urban growth, and human health. As a result, in this research, a 1000-meter buffer zone was established surrounding residential areas to evade community objection. A buffer zone of below 1000 m and more than 2000 m was deemed undesirable and extremely suitable, respectively.

AHP Application

The AHP approach and the GIS tool were used to analyze the morphological, environmental, and socioeconomic considerations because they were unlike in nature, described in diverse units, and partly or entirely inconsistent (Kamdar et al. 2019). Weights have been assigned to several criteria through AHP. Each decisive factor was given a 'Weight' based on the author's knowledge of the local circumstances, including the local MSWM scenario (Kamdar et al. 2019). The AHP technique was used up to produce the weight for the main "criteria and sub-criteria". AHP is a widely accepted decision-making technique for evaluating data for the valuation of acceptable land-fill sites using a GIS application. The AHP method is carried out in three main phases. The first stage is to analyze the decision-making process into a hierarchical structure, as shown in Fig. 2. A 'pair-wise comparison' is used to calculate weights for the different criteria in the following step of AHP. A criterion's weight is calculated by rating its importance and compatibility. Expert judgment is used to complete the assessment of the pair-wise comparisons. A 1-9 point scale developed by Kamdar et al. (2019) and Saaty (1990) can be used to compare various criteria, as presented in Table 1. Based on expert opinion and AHP pairwise comparisons, Table 3 illustrates the final weights employed for land-fill site selection in the research region using the 'AHP approach'(Kamdar et al. 2019). The very last step is to check the consistency ratio. Eq. (1) represents the mathematical form for calculating CR.

Table 1: Saaty's 1-9 scale for AHP (Penki et al. 2022, Saaty 1990).

Conceptual-Scale	Intensity of Importance	Inverse
Extremely-importance	9	1/9
Very strong to extremely-importance	8	1/8
Very strongly importance	7	1/7
Strongly to very strongly importance	6	1/6
Strongly importance	5	1/5
Moderately to strongly the importance	4	1/4
Moderately importance	3	1/3
Equally to moderate importance	2	1/2
Equally importance	1	1

$$CR = CI/RI \quad \ldots(1)$$

Where, CI is the consistency index and RI is the random index or mean consistency index, depending on the size of the matrix. Eq. (2) describes the mathematical formulation for calculating the CI.

$$CI = (\lambda_{max} - n)/n - 1 \quad \ldots(2)$$

Where n is the matrix size (n x n) and λ_{max} is the principal eigenvalue. Table 2 shows the RI values used for various matrix sizes.

In general, the CR should be less than 0.10 (i.e., 10%), to ensure the matrix's consistency, while a CR greater than 0.10 implies inconsistency in the expert's judgments, requiring re-evaluation. The ArcGIS 10.3 tool was utilized in this study to integrate the various map layers and their weights. To put the various data layers into a single spatial resolution, a base map of 931m was utilized for the overall data collection. Following that, the several maps with various weights are overlaid using the raster calculator tool in GIS. Using the following mathematical Eq. (3), the weights of the individual criteria were added to obtain the landfill suitability index.

$$LSI = \sum_{i=1}^{n} w_i * r_i \quad \ldots(3)$$

Table 2: Random index (RI)(Penki et al. 2022).

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54

Table 3: Suitability ranking of factors.

Main criteria	Param	Sub-Class	Risk Vulnerability	Rank	Parameter weight	Sub-Class weight [%]
Morphological perspective	Slope	0-3	Highly-suitable	1	0.079	49
		3-6	Suitable	2		27
		6-13	Moderately-suitable	3		14
		13-25	Less-suitable	4		8
		> 25	Un-suitable	5		2
	Elevation	< 40	Suitable	1	0.081	66
		40-80	Moderately-suitable	2		18
		80-20	Less-suitable	3		10
		> 120	Un-suitable	4		6
	Soil Texture	Loam	Highly-suitable	1	0.065	55
		Sandy clay loam	Suitable	2		24
		Sandy loam	Moderately-suitable	3		21
Environmental perspective	LULC	Waterbody/River	Un-suitable	6	0.051	3
		Vegetation	Suitable	2		25
		Settlement	Less-suitable	4		7
		Agriculture land	Moderately-suitable	3		13
		Bare soil	Highly-suitable	1		48
		Wetlands	Un-suitable	5		4
	Surface water	< 300	Un-suitable	4	0.217	7
		300-600	Moderately-suitable	3		16
		600-900	Suitable	2		25
		> 900	Highly-suitable	1		52
	Ground water table	0-1.5	Un-suitable	4	0.199	6
		1.5-3	Less-suitable	3		14
		3-4.5	Moderately-suitable	2		22
		> 4.5	Highly-suitable	1		58
Socio-economic perspective	Road network	< 250	Un-suitable	4	0.044	6
		250-500	Less-suitable	3		14
		500-1000	Moderately-suitable	2		27
		> 1000	Highly-suitable	1		53
	Historical Areas	< 1000	Un-suitable	5	0.043	4
		1000-1500	Very less-suitable	4		6
		1500-2000	Less-suitable	3		12
		2000-2500	Moderately-suitable	2		22
		> 2500	Highly-suitable	1		56
	Residential areas	< 1000	Un-suitable	4	0.221	5
		1000-1500	Less-suitable	3		10
		1500-2000	Moderately-suitable	2		24
		> 2000	Highly-suitable	1		61

Table 4: Areal extent of suitability index.

S. No.	suitability classes	Range	Area In Hectare	% Area
1.	Un-Suitable	9.61-22.87	180925.7559	28.84
2.	Less-Suitable	22.87-29.75	190001.9383	30.28
3.	Moderately-Suitable	29.75-36.8	178736.7104	28.49
4.	Suitable	36.8-52.4	77681.9563	12.39

Where r_i is the rating of criterion i, n is the number of param, and w_i is the weight of criterion i.

RESULTS AND DISCUSSION

This study resulted in the development of suitability maps (Fig. 2) for the different criteria considered. The final map displays the areas that are unsuitable, less suitable, moderately suitable, and suitable. Fig. 4 and Table 4 display the suitable index map as well as its areal extent, respectively. A 'suitability index map' of the research region was generated by combining all of the weighted criteria in an overlay analysis. A total land area of 627346.3609 hectares, reflecting 28.84%, was categorized as unsuitable, 30.28% as less suitable, 28.49% as moderately suitable, and 12.39% as suitable. The land-fill site assortment in the study area was based on a combination of morphological, environmental, and socioeconomic factors, as well as GIS and MCE methodologies.

As previously mentioned, the data was gathered from various sources and in various formats (such as raster and shapefile), but they were ultimately converted into raster format by executing of GIS tool. However, it should be noted

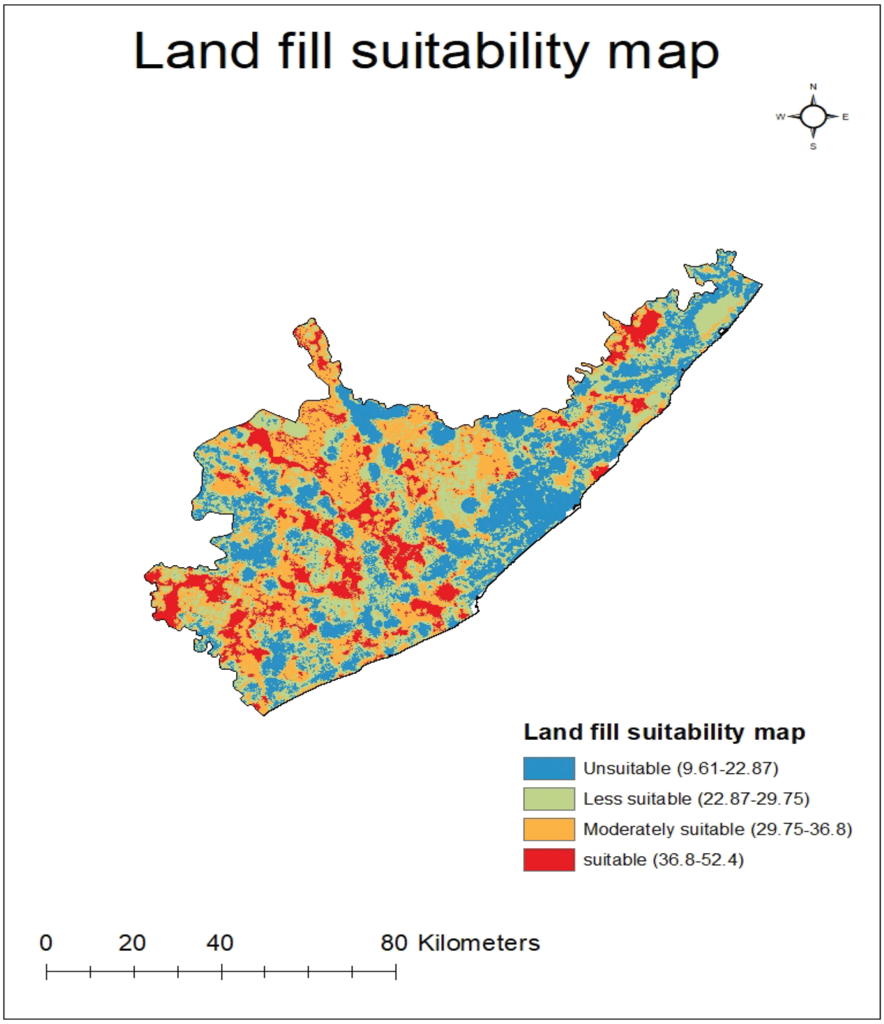

Fig. 4: Final landfill suitability map.

that all files must have the same cell size and coordinate system after conversion to raster format.

On the final map, there are some values that denote areas that are unsuitable, less suitable, moderately suitable, and suitable; these values were taken using the AHP as a core. Greater impact areas receive more weight in the AHP process, and lesser impact areas receive less weight. As a result, areas with high values on the final map are best suited for landfill disposal.

It's worth noting that the approach has worked well and produced accurate results for landfill site selection that was in line with field observations. Additionally, before making a final decision on the best site, it is recommended that they be further evaluated according to other local criteria and field investigations since some of these criteria must be explored in landfills, as described by the requirements of the landfill environmental impact assessment regulation. Finally, the applied technique employed in the study may be used as a reference for establishing the best site selection choice for MSW dumps, as well as a framework for future research in other disciplines.

CONCLUSIONS

A landfill site selection is complex and challenging that demands a high level of complex tasks that requires a substantial balance between morphological, environmental, and socioeconomic considerations. The ideal location for dump sites in the Srikakulam district was investigated using an MCDM approach that was used in a GIS platform. It is advised that the findings of the study be compared to those acquired from field investigations to select the most acceptable landfill-building sites. Additional studies, such as thorough geological and geotechnical investigations, public acceptability surveys, a waste inventory, and the evaluation of building appropriateness, should be conducted in selected locations.

In the case of landfills, implementing landfill site taxes would put together a more expensive waste management preference, which would reduce waste dumped into landfills. A landfill tax would encourage households to recycle more of their waste as the municipality would use a unit-based pricing system to charge households for the high costs of landfills. Further, the landfill tax policies would encourage waste prevention and recycling so that landfilling would become more financially attractive as well as encourage waste-to-value technology.

Insofar as this study's approach is scientific, its outcomes are likely to be an efficient tool for decision-makers, planners, and stakeholders. This is because they can decide where to site landfills in the future. Furthermore, this strategy can assist decision-makers in solving waste management problems by completing decision analysis functions for landfill dumping. Also, the strategy used in this study could be easily applicable to other regions of the world where landfill siting is a major issue.

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