GEOGRAPHICAL ANALYSIS

ORIGINAL ARTICLE

Geospatial Analysis of Landfill Site Suitability in Warangal District, India

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Abstract

The process of finding appropriate landfill locations serves as an essential requirement that guarantees environmentally responsible waste treatment methods. The research establishes landfill site suitability through geospatial analysis in Warangal District, India, which uses multi-criteria decision-making methods. The study evaluated multiple environmental and socio-economic factors, which included slope elevation, rainfall, land use/land cover, and distances to settlements, roads, and railways and lineaments. The Analytical Hierarchy Process (AHP) enabled weight distribution to be executed through assessment of criterion significance, and the final suitability map was produced through weighted overlay analysis. The study area contains only 2.52 square kilometers, which represents 0.09 percent of the area that meets requirements for landfill development while approximately 316.90 square kilometers of land demonstrates moderate suitability. The majority of the region falls under not suitable zones due to the presence of settlements, agricultural land and environmental constraints. The study results show that suitable landfill sites exist in limited supply which creates a requirement for proper waste management planning. The framework established through this research enables proper landfill site selection which promotes effective waste management in areas that experience fast urban development.

Keywords: Landfill, Geospatial analysis, AHP, Weighted overlay, GIS, Suitability analysis, Solid Waste, Decision making, Slope elevation, Suitable zone

1 Introduction

People produce waste every day through their common activities, which result in leftover food, packaging materials, old clothes, and electronic waste. The proper management of municipal solid waste is essential for environmental protection and human health safety. The mismanagement of waste materials results in environmental contamination through land, water, and air pollution, which increases disease transmission and ecological damage[5, 9].

Landfilling operates as the primary waste disposal method because it offers both economical waste management and simple operational procedures. The process includes the regulated disposal of waste materials in specific locations. The selection of improper landfill sites causes groundwater pollution and generates unpleasant odors while creating air contamination problems and raising disputes with

residents[4, 22]. Landfill site selection functions as an essential element within sustainable waste management systems.

1.2 Suitability and Its Importance for Warangal

Landfill site suitability refers to the identification of locations that minimize environmental, social, and economic risks associated with waste disposal. A suitable site should be located away from settlements, water bodies, and agricultural lands while assessing physical and environmental factors, which include slope, rainfall, and geological conditions. Proper site selection helps reduce risks, which include groundwater contamination, soil pollution, and public health hazards[7, 10, 17].

The process becomes crucial for areas that experience rapid growth and suffer from limited land availability. Warangal District in Telangana is experiencing increasing urbanization and population growth, which has led to a rise in municipal solid waste generation. The region consists of a combination of agricultural land, residential areas, and water bodies, which include tanks and lakes, and existing transportation systems. If landfill sites are located incorrectly in this type of environment, it results in water contamination, agricultural loss, and community disputes[1, 18].

The identification of appropriate landfill sites in Warangal is necessary for protecting the environment while allowing urban development to proceed. The scientific suitability method assists organizations in decreasing risks while meeting regulatory requirements and implementing environmentally sustainable land use design.

1.3 Role of Spatial Analysis in Site Selection

Selecting a landfill site requires simultaneous assessment of various environmental and socio-economic parameters, which include land use and slope, hydrology, and distance from infrastructure. Traditional methods for managing these factors create challenges that typically result in less precise outcomes[13, 19].

Spatial analysis techniques enable researchers to combine different datasets while offering a standardized method to assess the suitability of particular sites. Spatial-based suitability analysis has become the preferred approach for selecting landfill sites in environmental planning research because it has gained widespread acceptance.

2 Study Area

Warangal District is located in the northeastern part of Telangana and forms part of the Deccan Plateau. The district features a landscape that consists of gently rising hills together with flat areas and low hills. The urban area consists of three cities Warangal City Hanamkonda and Kazipet which have undergone significant development during the past years.

The area experiences tropical weather conditions which produce yearly rainfall between 900 and 1200 millimeters that falls mainly during the southwest monsoon season. The land exhibits multiple uses which include agricultural fields built-up environments forest areas barren spaces and multiple water bodies that include tanks and lakes.

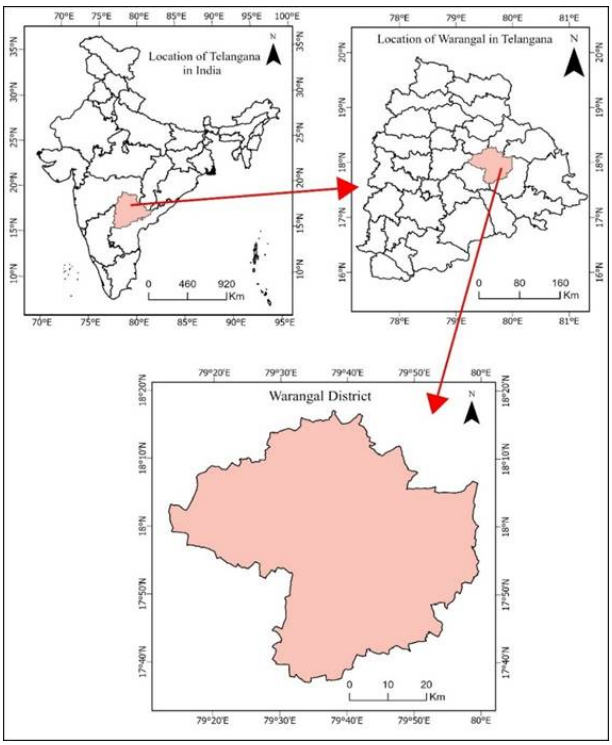


Fig. 1: Study Area

The area uses agriculture as its primary land use method which creates problems for waste disposal because it limits available land space. The district has experienced more waste generation because of both increasing population numbers and urban development activities. The process of establishing landfill sites becomes difficult because of the existing settlements and agricultural fields and water bodies in the area.

The area needs specific locations to be identified through a detailed process because these sites will establish environmental safety measures while enabling efficient waste management practices according to sustainable methods.

3 Data Sets and Methodology

3.1 Data Sets

The present study uses multiple spatial datasets to evaluate landfill site suitability in Warangal District. These datasets contain information about topographic features and environmental conditions, and socio-economic factors that determine site selection.

Table 1: Data sources and description

Data Layer	Description	Source	Resolution
Elevation (DEM)	Digital Elevation Model	Open Topography (Copernicus DEM)	30 m
Slope	Derived from DEM	Derived	30 m
Aspect	Derived from DEM	Derived	30 m
Land Use/Land Cover	Agricultural, built-up, forest, etc.	Satellite-based LULC	30 m
Settlements	Built-up areas	Geofabrik	Vector
Roads	Transport network	Bhukosh	Vector
Railways	Railway network	Bhukosh	Vector
Rainfall	Precipitation data	CHIRPS[6]	5 km
Lineaments	Geological features	Bhukosh	Vector

3.2 Data Pre-Processing

All datasets followed preprocessing procedures that ensured their consistency and accuracy throughout the entire process. All the inputs were reprojected and resampled to maintain the uniformity in spatial extent and projection.

3.3 Selection of Criteria

Nine Parameters were selected based on previous landfill suitability studies and environmental guidelines. The Parameters include slope, elevation, rainfall, land use/land cover, distance to settlements and roads, and railways, lineaments, and aspect. The three factors of environmental safety and accessibility and socio-economic factors, which are essential for landfill site selection[13, 19].

3.4 AHP Analysis

Thomas L. Saaty developed the Analytical Hierarchy Process (AHP) according to his work published in 1980 which he established as a method for determining relative criterion importance[15]. The researchers built a pairwise comparison matrix to assess the landfill suitability criteria according to their respective impacts on the suitability of landfills.

The priority vector is calculated as the average of each row in the normalized matrix. To confirm that the matrix is consistent, we need to calculate the Consistency Ratio (CR).

This involves calculating the Consistency Index (CI) and comparing it with the Random Index (RI) for the given number of parameters.

Consistency Check:

1. Calculate the Weighted Sum Vector: Original AHP matrix * Priority vector.

2. Compute the Consistency Index:

$CI = \lambda max - n / n - 1$

Where λmax is the average of the elements of the weighted sum vector divided by the priority vector, and n is the number of parameters.

3. Calculate the Consistency Ratio:

$CR = CI/RI$

Where RI is the Random Index for the corresponding number of parameters.

Random Index (RI) n = 9, the RI value is 1.32.

λmax: 7.624

Consistency Index (CI): 0.025

Consistency Ratio (CR): 0.017

A Consistency Ratio (CR) of less than 0.1 (10%) shows that the pairwise comparisons are consistent. Since the CR here is about 0.017, which is acceptable.

Table 2: Comparison matrix and relative score of each parameter

Criteria	Slope	Elevation	Rainfall	LULC	Lineaments	Roads	Railways	Settlements	Aspect
Slope	1	3	3	3	3	3	3	3	5
Elevation	1/3	1	1	2	2	2	2	2	3
Rainfall	1/3	1	1	2	2	2	2	2	3
LULC	1/3	1/2	1/2	1	2	2	2	2	2
Lineaments	1/3	1/2	1/2	1/2	1	2	2	2	2
Roads	1/3	1/2	1/2	1/2	1/2	1	1	2	2
Railways	1/3	1/2	1/2	1/2	1/2	1	1	2	2
Settlements	1/3	1/2	1/2	1/2	1/2	1/2	1/2	1	2
Aspect	1/3	1/3	1/3	1/2	1/2	1/2	1/2	1/2	1

Table 3: Normalized pairwise comparison matrix

Criteria	Slope	Elevation	Rainfall	LULC	Lineament	Road	Railway	Settlement	Aspect	Weight
Slope	0.33	0.36	0.36	0.28	0.28	0.24	0.24	0.22	0.37	0.3
Elevation	0.11	0.12	0.12	0.19	0.19	0.16	0.16	0.15	0.22	0.16
Rainfall	0.11	0.12	0.12	0.19	0.19	0.16	0.16	0.15	0.22	0.16
LULC	0.11	0.06	0.06	0.09	0.19	0.16	0.16	0.15	0.15	0.13
Lineaments	0.11	0.06	0.06	0.09	0.09	0.16	0.16	0.15	0.15	0.12
Roads	0.11	0.06	0.06	0.09	0.09	0.08	0.08	0.15	0.15	0.1
Railways	0.11	0.06	0.06	0.09	0.09	0.08	0.08	0.15	0.15	0.1
Settlements	0.11	0.06	0.06	0.09	0.09	0.08	0.08	0.07	0.15	0.1
Aspect	0.07	0.04	0.04	0.06	0.06	0.08	0.08	0.07	0.07	0.06

Table 4: Weighted Sum, Weights, and Consistency Ratio Calculation

Criteria	Weight	Sum	Ratio
Slope	0.3	2.76	9.2
Elevation	0.16	1.45	9.06
Rainfall	0.16	1.46	9.13
LULC	0.13	1.2	9.15
Lineaments	0.12	1.1	9.18
Roads	0.1	0.91	9.09
Railways	0.1	0.9	9.02
Settlements	0.1	0.91	9.07
Aspect	0.06	0.54	9.04

3.5 Criteria for Reclassification

All the parameters that were taken are reclassified and assigned weights and ranks. The process of reclassification decreases data variability while ensuring that thematic layers maintain their integrated value during overlay analysis. The system enables users to combine multiple datasets which have different measurement units and scaling systems into a unified analysis framework. The assessment used a five-point system, which assigned each parameter a value from 1 to 5, with 1 indicating highly suitable areas and 5 indicating least suitable areas. The classification ranges were defined based on standard landfill siting guidelines and previous studies.

The study found that low slope areas, which had slopes between 0 and 2 degrees, were deemed highly suitable, but the research classified areas that were near settlements and water bodies as unsuitable. The new classification system enables researchers to assess all criteria through direct comparison, which they can use to conduct weighted overlay analysis.

Table 5: Reclassification Criteria and Suitability Ranking for Landfill Site Selection

Criteria	Weight (%)	Class	Rank (1 best, 5 worst)
		0–2°	1
		2–4°	2
Slope	20	4–6°	3
		6–8°	4
		>8°	5
		198–300 m	1
		300–400 m	2
Elevation	12	400–500 m	3
		500–600 m	4
		>600 m	5
		>1300 mm	1
		1200–1300 mm	2
Rainfall	12	1100–1200 mm	3
		1000–1100 mm	4
		<1000 mm	5
		Barren/Wasteland	1
		Agricultural land	2
LULC	12	Forest/Vegetation	3
		Built-up	4
		Water bodies	5
		>3000 m	1
		2000–3000 m	2
Distance to lineaments	10	1000–2000 m	3
		500–1000 m	4
		0–500 m	5
		Flat	1
		North	2
Aspect	8	East	3
		South	4
		West	5
		>3000 m	1
		2000–3000 m	2
Distance to settlements	12	1000–2000 m	3
		500–1000 m	4
		0–500 m	5
		>2000 m	1
		1000–2000 m	2
Distance to roads	7	500–1000 m	3
		250–500 m	4
		0–250 m	5
		>3000 m	1
		2000–3000 m	2
Distance to railways	7	1000–2000 m	3
		500–1000 m	4
		0–500 m	5

3.6 Weighted Overlay Analysis

The weighted overlay analysis to create a suitability map through the combination of all reclassified thematic layers. The method enables multiple criteria assessment through weight assignments to each layer which reflects its importance based on AHP analysis results[3, 12].

Thematic layers underwent reclassification which included slope and elevation and rainfall and land use/land cover and distance to settlements and roads and railways and lineaments and aspect to create a unified suitability scale that measures from 1 (highly suitable) to 5 (least suitable).

The GIS tools created a composite suitability map through the process of multiplying each raster layer by its corresponding weight after completing the reclassification. The resulting map represents the overall suitability of different locations for landfill site selection, where higher values indicate more favorable conditions and lower values represent unsuitable areas[7].

The final suitability map divided into different categories which included highly suitable and moderately suitable and less suitable and unsuitable zones.

4 Results and Discussion

The study area shows different environmental and physical conditions through spatial analysis, which evaluates its individual thematic layers. The slope map shows that the majority of the region exists within low slope classes which extend from 0 to 2 degrees because these slopes offer both reduced erosion risk and simplified construction processes which make them ideal for landfill development. The area contains only a few higher slope regions which exist as small hill sections.

The district displays moderate elevation differences because most areas match the appropriate landfill development range. The land use/land cover analysis shows that agricultural land covers most of the area while built-up areas and water bodies follow behind. The two areas, which include agricultural land and built-up space function as unsuitable sites which decrease the number of available landfill locations.

Distance-based criteria such as proximity to settlements, roads, and railways show that many areas fall within restricted buffer zones, reducing suitability. The rainfall distribution pattern shows moderate precipitation levels

which create leachate generation risk that needs to be managed through appropriate site selection process.

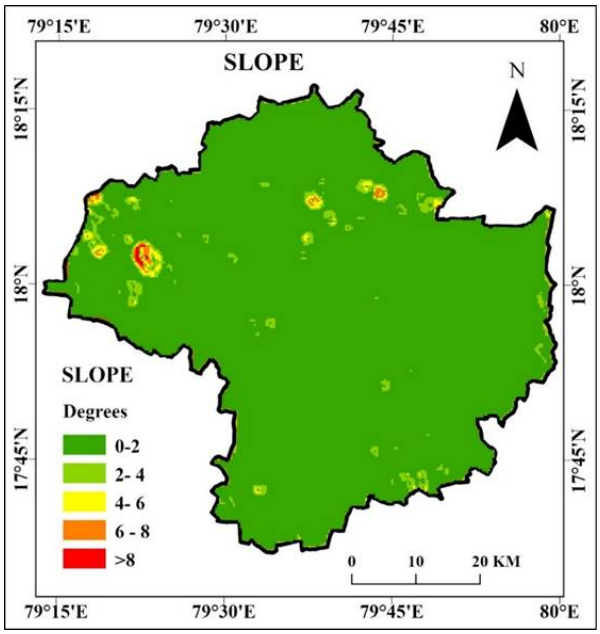


Fig. 2: Slope Map

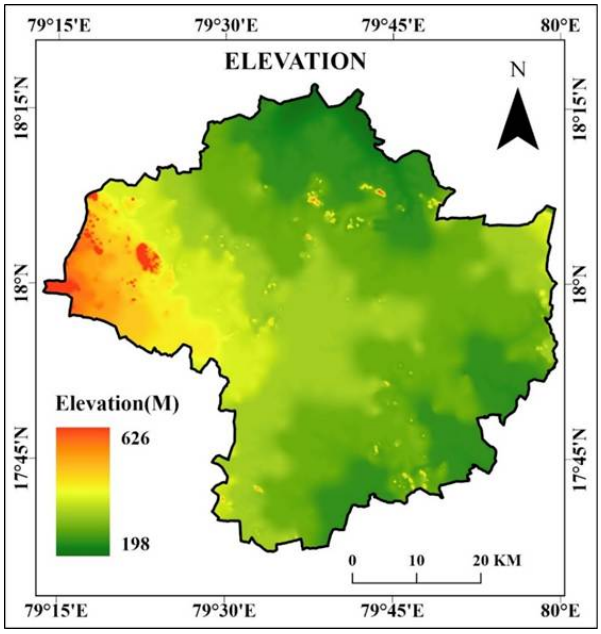


Fig. 3: Elevation Map

4.2 AHP Weight Influence

The Analytical Hierarchy Process (AHP) was used to determine the relative importance of each criterion in

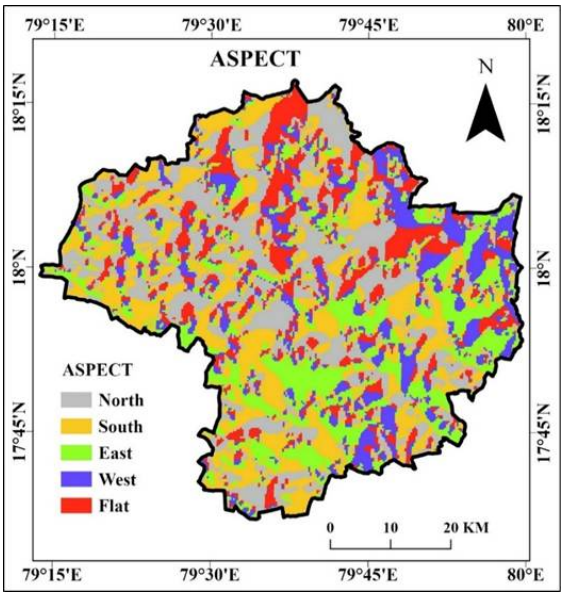


Fig. 4: Aspect Map

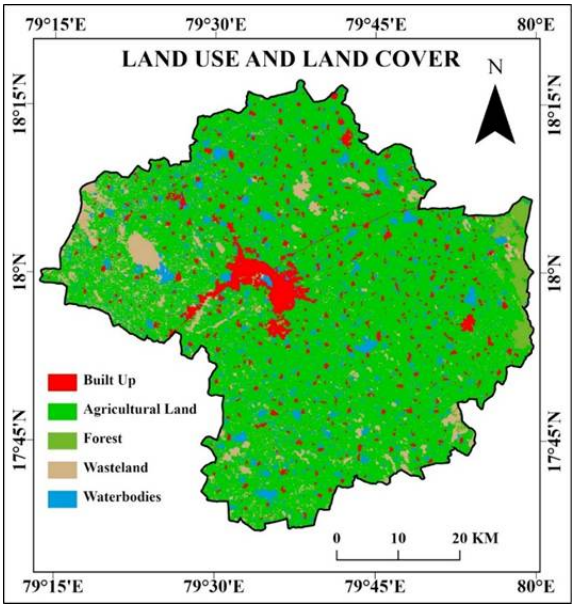


Fig. 5: LULC Map

landfill site suitability analysis. The results show that slope has the highest weight (30%) which shows that terrain conditions represent a major factor in site selection.

The elevation and rainfall parameters received moderate weights of 16% each because they control drainage patterns and leachate generation. The study found that land use/land cover (12%) and distance to lineaments (10%)

present substantial environmental safety and groundwater protection risks.

The study assigned moderate weights to distance-based criteria which included distance to settlements (12%) roads (7%) and railways (7%) because they require safe buffer distances yet provide necessary access.

The study assigned aspect (6%) the lowest weight because it shows less impact than other elements. The weight distribution shows that physical and environmental factors determine landfill suitability more than locational factors. The final suitability analysis uses balanced weighting to evaluate environmental protection and accessibility factors.'

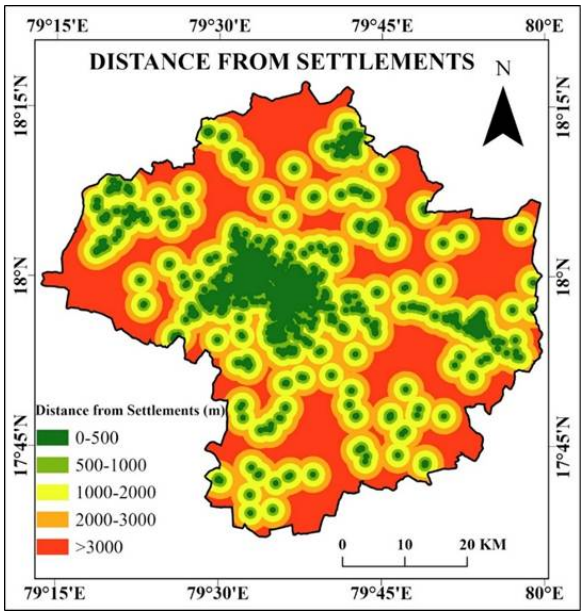


Fig. 6: Distance to Settlements

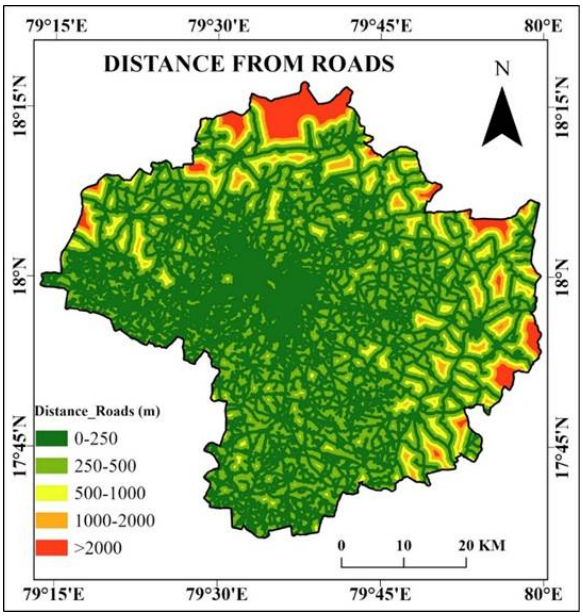


Fig. 7: Distance to Roads

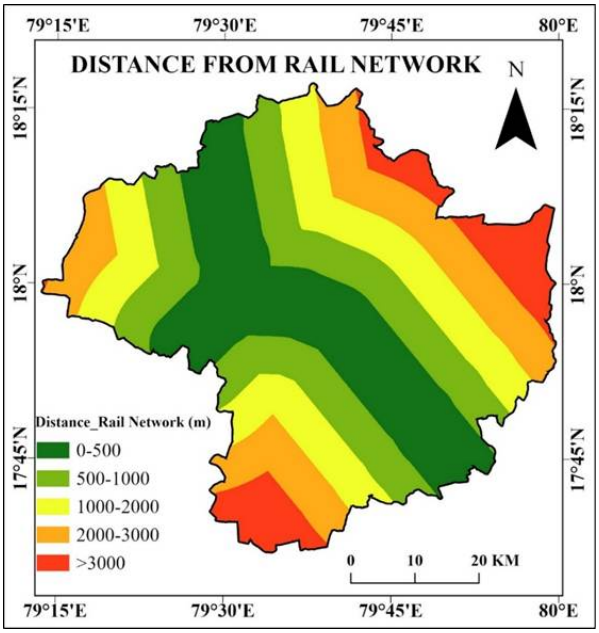


Fig. 8: Distance to Railways

4.3 Landfill Suitability Map

The weighted overlay analysis produced a landfill suitability map which divided the study area into three distinct categories: highly suitable areas and moderately suitable areas and not suitable areas. The spatial distribution shows that not suitable areas occupy most of the district which extends across the majority of the area. The district contains only a few areas which meet high suitability standards and those areas exist as small, scattered patches which mainly occupy the northwestern and southern regions. The areas exist as locations which have optimal slope conditions and suitable elevation and adequate space between them and residential areas and protected territories. The district's central region contains its moderately suitable areas which exist as disjointed sections throughout the territory.

The zones satisfy certain necessary requirements for landfill development, but they need engineering solutions which include proper lining and leachate management

systems. Not suitable areas make up most of the territory because agricultural land and settlements and environmental restrictions which include water body proximity and infrastructure elements exist throughout the area.

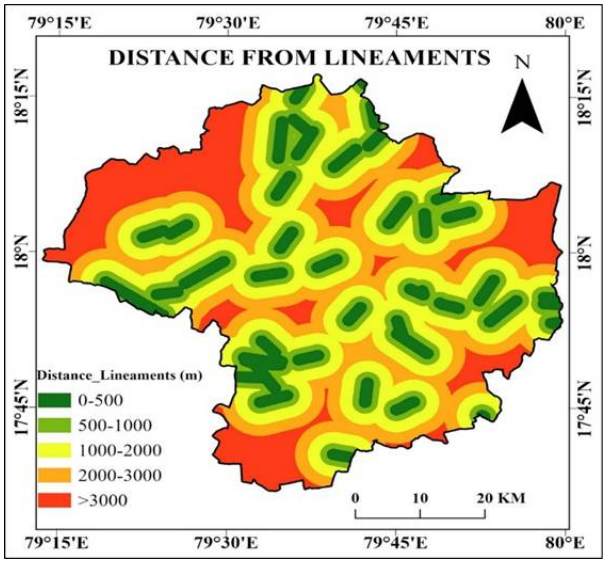


Fig. 9: Distance to Lineaments

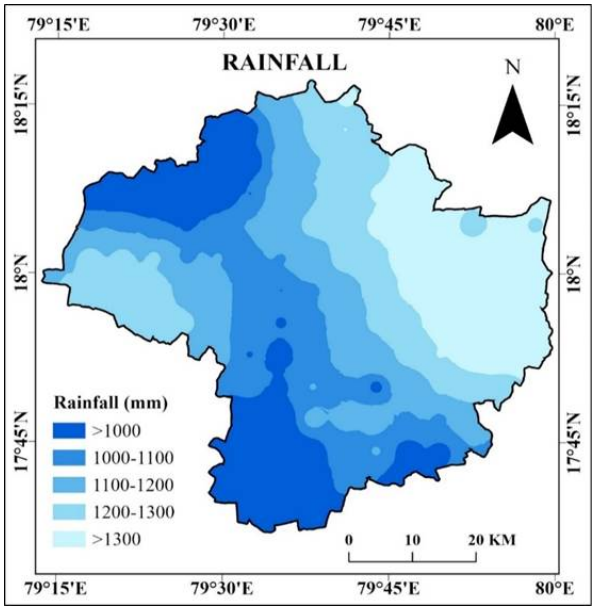


Fig. 10: Rainfall Map

4.4 Area Statistics

The spatial analysis of landfill suitability shows that suitable areas across the study area display different levels of distribution. The total study area of Warangal District is approximately 2927 km². The highly suitable areas for the project cover only 2.52 km² which demonstrates that there are very few suitable sites for landfill construction. The moderately suitable areas extent to 316.90 km².

The majority of district land area exists in the not suitable category because agricultural land and settlements and water bodies and other environmental factors exist throughout the area.

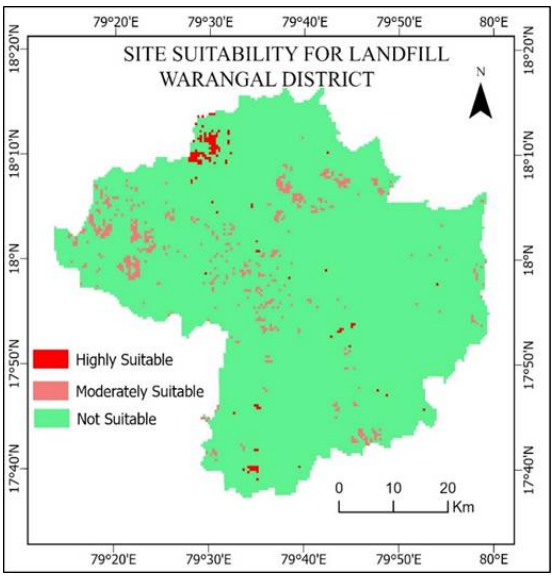


Fig. 11: Landfill Site Suitability Map of Warangal District

Table 6: Area Distribution of Landfill Suitability Classes

Suitability Class	Area (km²)	Percentage (%)
Highly Suitable	2.52	0.09%
Moderately Suitable	316.9	10.83%
Not Suitable	2607.58	89.08%
Total	**2927**	**100%**

5 Conclusion

This study evaluated landfill site suitability in Warangal District using a multi-criteria approach which combines AHP with weighted overlay analysis. The results show that only a very small portion of the area (about 2.52 km², ~0.09%) is highly suitable while moderately suitable areas cover around 316.90 km². The majority of the district exists in not suitable zones because settlements and agricultural land together with environmental restrictions create these areas. The findings show that suitable landfill sites exist in limited and dispersed locations. The region requires planning combined with proper engineering methods for

using moderately suitable areas to achieve sustainable waste management that protects the environment.

6 Future Works

Future studies can improve landfill suitability analysis by incorporating additional parameters which include groundwater depth and soil permeability and detailed hydrogeological data. The implementation of higher resolution datasets together with field-based validation procedures will lead to improved result accuracy. Time-series analysis serves as a tool to evaluate transformations in both land use patterns and urban development. Decision-making processes achieve greater accuracy through the combination of advanced methods which include machine learning and fuzzy logic techniques. Future planning needs to include social economic elements together with community acceptance aspects as additional factors. The research study needs to extend its scope by including different areas to test various environmental conditions in order to create more flexible landfill siting models.

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