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GIS-Based Landfill Site Suitability Analysis in Deogarh Municipal Area: A Geographical Study

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Abstract: The rapid increase in municipal solid waste (MSW) resulting from population growth, urbanization, and changing consumption patterns has emerged as a major environmental challenge in developing countries. Scientific landfill site selection is essential to minimize adverse environmental and public health impacts while ensuring sustainable waste management. The present study aims to identify suitable landfill sites in the **Deogarh Municipal Area**, **Rajsamand District, Rajasthan**, using **Geographic Information System (GIS)** and **Multi-Criteria Decision Analysis (MCDA)**. Spatial datasets, including land use/land cover, road networks, water bodies, built-up areas, agricultural land, railway lines, and slope, were acquired through field surveys and secondary data sources and processed using **QGIS**. Buffer analysis and weighted overlay techniques were applied in accordance with the **Solid Waste Management Rules, 2016**, and the guidelines of the **Central Pollution Control Board (CPCB)** to evaluate landfill site suitability. The integrated analysis classified the study area into different suitability zones ranging from unsuitable to highly suitable. The results indicate that the existing dumping site is environmentally less suitable because of its proximity to residential areas, agricultural land, and public institutions, thereby posing potential environmental and public health risks. In contrast, the proposed alternative sites are located on barren land with favourable environmental conditions, adequate road accessibility, and greater compliance with landfill site selection criteria, making them more suitable for future landfill development. The study demonstrates that the integration of GIS and MCDA provides a robust, reliable, and scientifically sound decision-support framework for landfill site selection. The proposed methodology can assist municipal authorities and planners in developing sustainable solid waste management strategies and may serve as a replicable model for other urban areas facing similar waste management challenges. The final suitability analysis showed that 12.4% of the study area falls under highly suitable class while 28.6% was moderately suitable.

Keywords: Municipal Solid Waste (MSW), Multi-criteria Decision Analysis (MCDA), Buffer Analysis, Landfill Site Selection, (GIS), QGIS, Spatial Analysis

1. INTRODUCTION

The rapid growth of population, urbanization, and changing consumption patterns have significantly increased the generation of municipal solid waste in urban areas across India. However, in many cities and towns, solid waste disposal is still carried out using conventional and unscientific methods, resulting in groundwater contamination, air pollution, foul odour, the spread of diseases, degradation of agricultural land, and ecological imbalance. These environmental and public health concerns highlight the urgent need for sustainable solid waste management practices.

The Solid Waste Management Rules, 2016, and the guidelines issued by the Central Pollution Control Board (CPCB) emphasize that landfill site selection should be based on environmental, social, and economic considerations to minimize adverse impacts on human health and the environment. In recent years, advanced geospatial technologies such as Geographic Information System (GIS), Remote Sensing (RS), and Multi-Criteria Decision Analysis (MCDA) have become effective tools for landfill site suitability analysis by integrating and evaluating multiple spatial and environmental parameters.

Deogarh Municipal Area, located in Rajsamand District, Rajasthan, is a historically significant and rapidly developing urban centre. Owing to population growth, urban expansion, and changing lifestyles, the quantity of municipal solid waste generated in the municipality has increased considerably over the years. The existing waste disposal site is inadequate to meet future waste management requirements and does not fully comply with environmental and scientific standards, thereby posing potential risks to environmental quality and public health.

Therefore, the present study aims to identify environmentally suitable landfill sites in the Deogarh Municipal Area using GIS-based spatial analysis. The study integrates key geographical factors, including land use/land cover, road networks, water bodies, residential areas, agricultural land, and slope, to prepare a scientifically reliable landfill site

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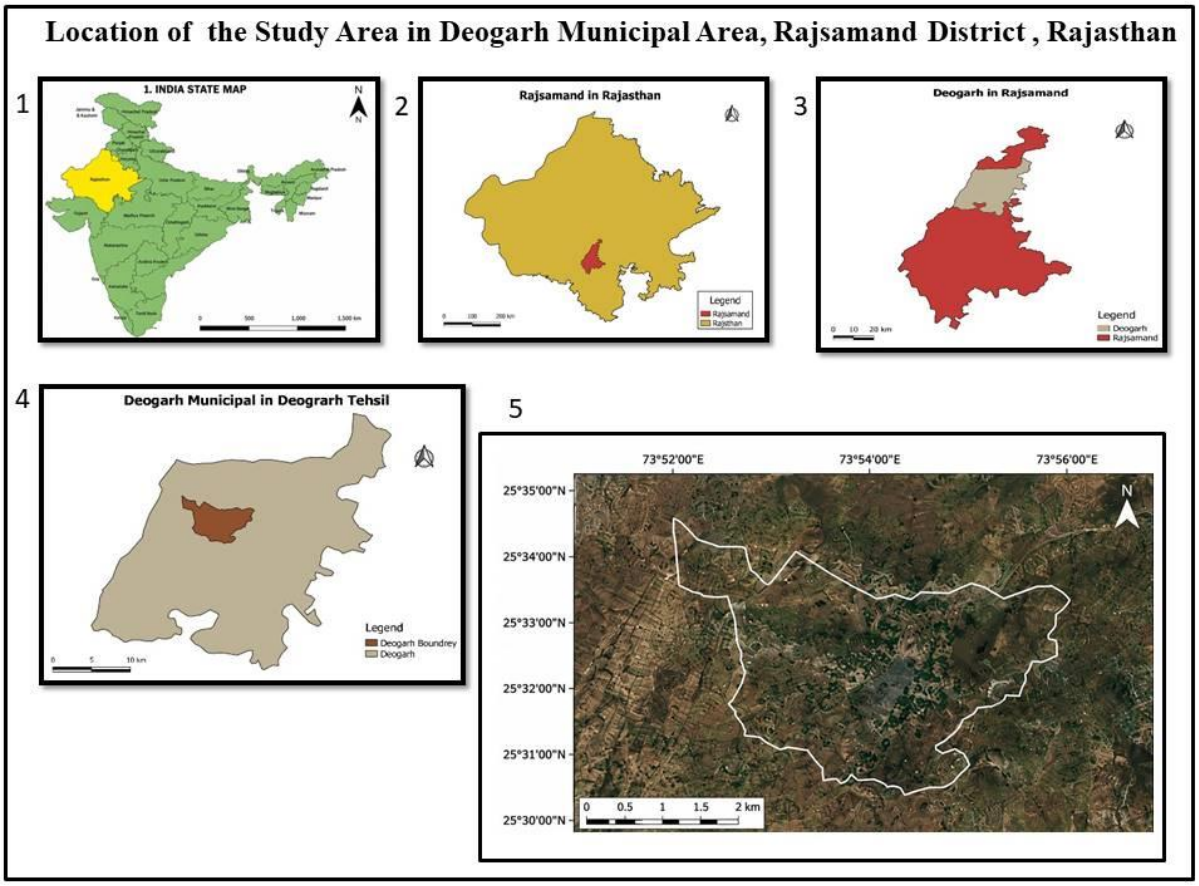
suitability map. The findings are expected to support sustainable solid waste management and assist local authorities in making informed planning and environmental management decisions.

2. STUDY AREA

The study was conducted in Deogarh Municipal Area, located in Rajsamand District, Rajasthan, India. Deogarh is an important urban centre situated in the Aravalli Mountain Range, which provides the region with distinct physiographic and environmental characteristics. Geographically, the town lies between 25.53° N latitude and 73.90° E longitude, at an average elevation of approximately 638 m (2,093 ft) above mean sea level. The municipal area is characterized by undulating topography, rocky terrain, and hilly landscapes associated with the Aravalli Range. The region is surrounded by rocky hills in the east, Kali Ghati (Aravalli Hills) in the west, Nathdwara Ghati in the south, and the Ajmer region to the north. A small lake located near the town further influences the local drainage and environmental conditions. These diverse physical features make the area suitable for geospatial analysis related to landfill site selection. Deogarh is well connected by road and is located approximately 4 km from National Highway-48 (formerly NH-8), which provides connectivity with major cities such as Udaipur, Ajmer, and Bhilwara. Road transport is the primary mode of accessibility, as the town is not directly connected by a broad-gauge railway network. The economy of Deogarh is primarily supported by agriculture, trade, tourism, and granite mining and polishing industries. In recent years, increasing population, urban expansion, and economic activities have led to a steady rise in municipal solid waste generation. The existing waste disposal system is insufficient to address future waste management needs, making Deogarh an appropriate case study for GIS-based landfill site suitability analysis.



3. METHODOLOGY

The present study aims to identify suitable landfill sites in the Deogarh Municipal Area using Geographic Information System (GIS) and QGIS techniques. A combination of primary and secondary data sources was employed to ensure a comprehensive spatial analysis.

Primary data were collected through field surveys, GPS observations, and site inspections to verify existing waste disposal locations and ground conditions. Secondary data were obtained from the Census of India (2011), Deogarh

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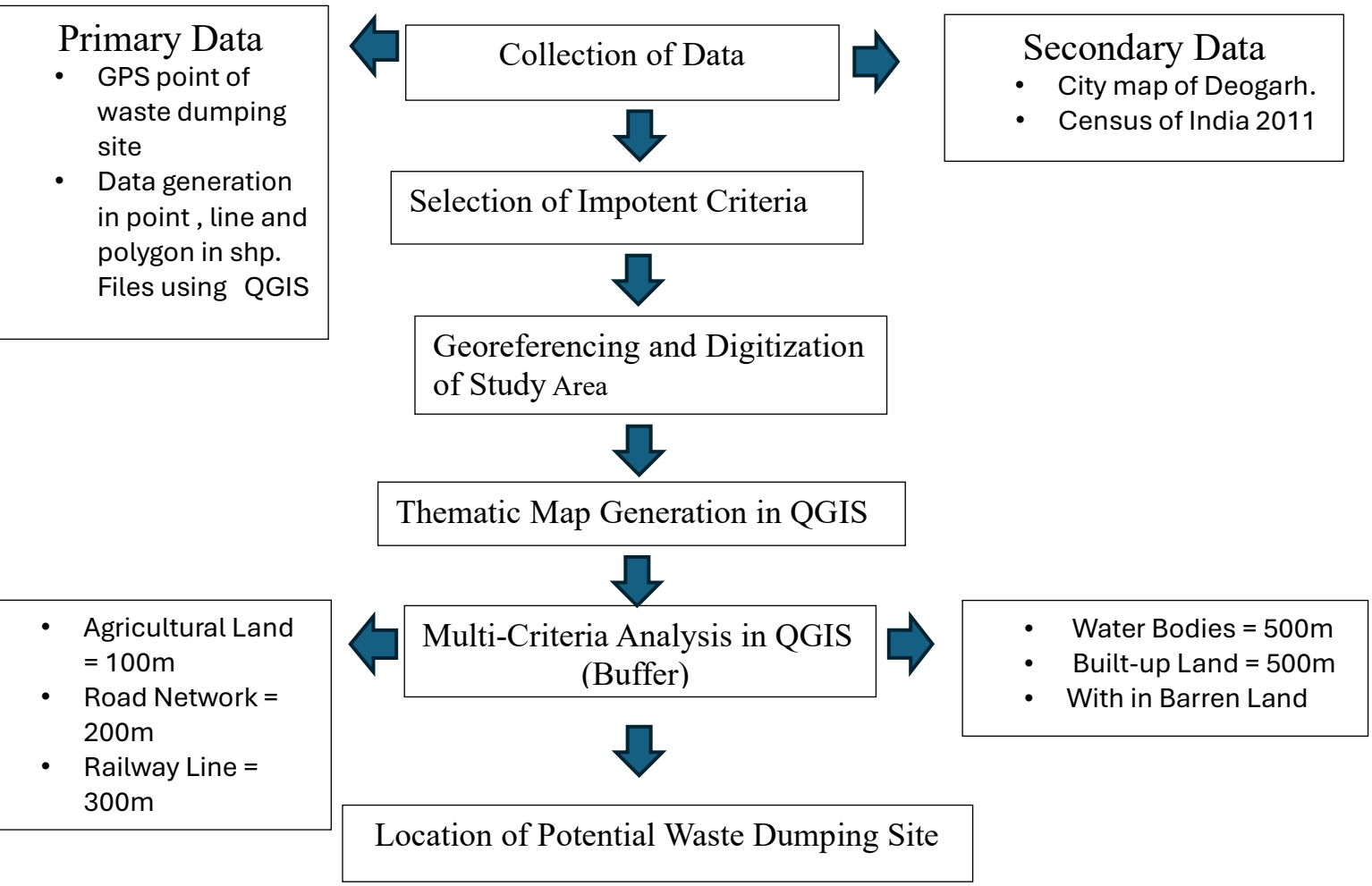
Municipal Council, Google Earth, satellite imagery, and other relevant government publications and geospatial databases.

The collected spatial data were processed in QGIS through georeferencing, digitization, and spatial database preparation. Based on the study objectives, thematic layers including land use/land cover, road network, water bodies, agricultural land, railway lines, built-up areas, and slope were generated. Buffer zones were created around environmentally sensitive features in accordance with the Solid Waste Management Rules, 2016, and the guidelines of the Central Pollution Control Board (CPCB) to identify restricted and permissible areas for landfill development.

The thematic layers were integrated using Overlay Analysis and Multi-Criteria Decision Analysis (MCDA) to evaluate the suitability of different locations for landfill site selection. Each criterion was analysed according to its environmental significance and spatial suitability. The integrated analysis produced a Landfill Site Suitability Map, which classified the study area into different suitability categories ranging from unsuitable to highly suitable.

The identified suitable sites provide environmentally sound and technically feasible locations for future landfill development. The proposed methodology supports scientific decision-making, minimizes adverse environmental impacts, and contributes to sustainable municipal solid waste management in the Deogarh Municipal Area.



Flow Chart of Methodology

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4. RESULTS

The present study evaluated the suitability of the existing municipal solid waste disposal site in the Deogarh Municipal Area using Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA). Spatial datasets, including land use/land cover, road network, water bodies, built-up areas, agricultural land, railway lines, and slope, were integrated to assess the suitability of the existing landfill site and identify environmentally appropriate alternative locations.

The analysis revealed that the existing disposal site is located in the south-western part of the Deogarh Municipal Area, approximately 2 km from the main urban settlement. The site has good road connectivity, facilitating efficient and economical transportation of municipal solid waste. However, buffer analysis indicated that residential areas, agricultural land, educational institutions, and other public facilities are located within 300–500 m of the disposal site. This proximity increases the potential risk of odour nuisance, groundwater contamination, soil degradation, air pollution, and adverse public health impacts.

The land use/land cover analysis showed that agricultural land is the dominant land use surrounding the existing disposal site, while residential development is gradually expanding towards the area. Analysis of drainage and surface water features indicated that, during the monsoon season, untreated leachate may be transported through surface runoff, potentially contaminating nearby agricultural land and water resources if adequate environmental safeguards are not implemented.

The GIS-based MCDA identified several alternative locations that are more suitable for future landfill development. These sites are characterised by lower population density, greater distance from residential areas and water bodies, favourable topographic conditions, and better accessibility through the existing road network. Based on the integrated suitability analysis, these locations were classified as the most appropriate for environmentally sustainable landfill development.

4.1 Existing Dumping Site Analysis

The GIS-based spatial analysis revealed that the existing municipal solid waste dumping site is located in the south-western part of the Deogarh Municipal Area. Although the site has good road accessibility, it is situated in close proximity to residential settlements, agricultural land, and public institutions. Buffer analysis indicated that several environmentally sensitive features fall within the prescribed restricted distance, making the existing dumping site environmentally unsuitable for long-term landfill development. The close proximity of these sensitive land-use features increases the potential risk of groundwater contamination, soil degradation, foul odour, leachate generation, and adverse public health impacts. Therefore, the existing dumping site does not fully comply with the Solid Waste Management Rules (2016) and CPCB guidelines.

4.2 Land Use/Land Cover Analysis

The Land Use/Land Cover (LULC) analysis showed that the study area consists of agricultural land, barren land, built-up areas, water bodies, and transportation networks. Agricultural land occupies a significant proportion of the municipal area, whereas barren land is mainly distributed towards the peripheral regions. Since landfill development on agricultural and built-up land may result in environmental degradation and socio-economic conflicts, these areas were assigned lower suitability scores. In contrast, barren land was identified as the most suitable land-use category due to its minimum ecological and socio-economic impact.

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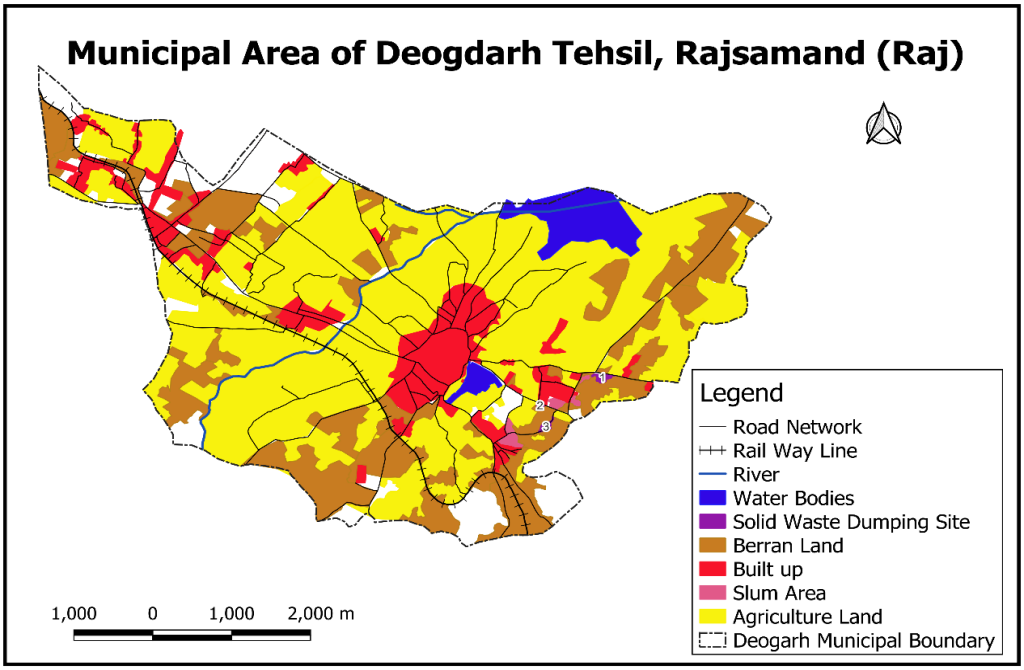

Figure 2: Land Use/Land Cover Map & Existing Dumping Site Map

4.3 Road Network Buffer Analysis

Accessibility is one of the most important criteria for landfill site selection. The road buffer analysis indicated that sites located at an appropriate distance from the road network provide better transportation efficiency while minimizing traffic congestion and environmental disturbance. Areas having adequate road connectivity but located outside the restricted buffer were identified as more suitable for landfill development.

4.4 Railway Line Buffer Analysis

The railway buffer analysis excluded areas located within the restricted distance from railway infrastructure. These zones were considered unsuitable because landfill operations near railway corridors may create operational and environmental hazards. The remaining areas outside the railway buffer were considered comparatively suitable for further evaluation.

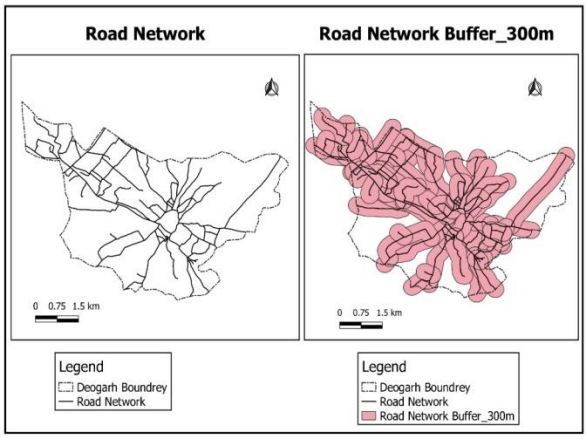

Figure 3: Road Network Buffer Map

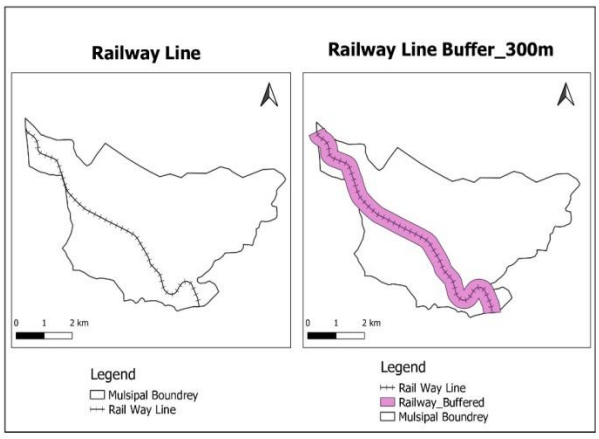

Figure 4: Railway Line Buffer Map

4.5 Water Bodies Buffer Analysis

Water bodies represent one of the most environmentally sensitive criteria in landfill site selection. Buffer analysis excluded all locations situated within the prescribed distance from lakes, ponds, and drainage channels. This restriction

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reduces the possibility of groundwater pollution and surface water contamination caused by landfill leachate. Consequently, areas located beyond the water-body buffer received higher suitability scores.

4.6 Built-up Area Buffer Analysis

The built-up area buffer analysis demonstrated that landfill sites should be located away from residential settlements to minimize odour, noise, air pollution, and public health risks. Areas falling within the restricted residential buffer were excluded from the suitability analysis, whereas locations situated beyond the buffer were considered environmentally more acceptable.

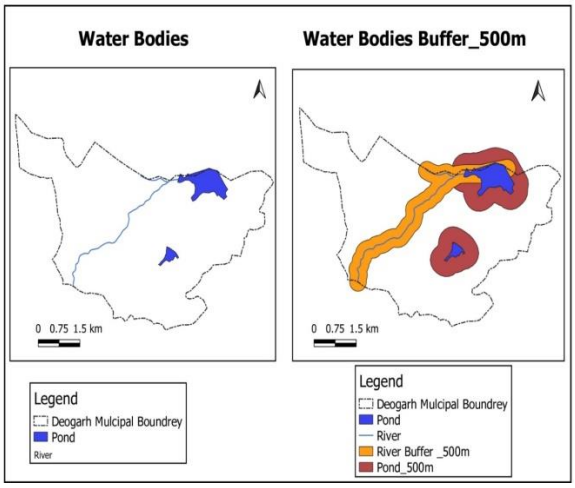

Figure 5: Water Bodies Buffer Map

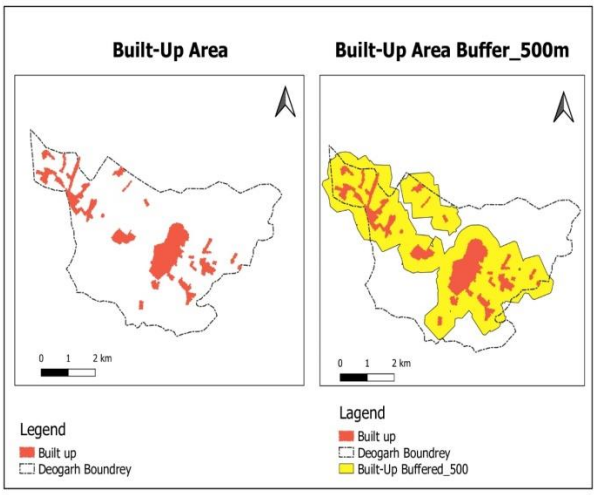

Figure 6: Built-up Area Buffer Map

4.7 Agricultural Land Buffer Analysis

Agricultural land was considered an environmentally sensitive resource and was therefore excluded from landfill suitability. Establishment of landfill facilities near agricultural land may reduce soil quality, affect crop productivity, and contaminate irrigation sources. Hence, barren land located away from cultivated areas was identified as a more appropriate option for future landfill development.

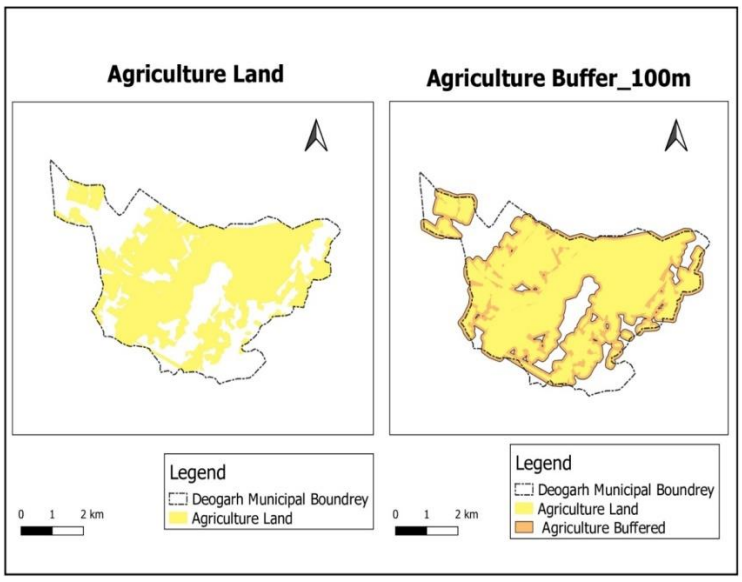

Figure 7: Agricultural Land Buffer Map

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4.8 Final Landfill Site Suitability Analysis

The integration of all thematic layers through GIS-based Multi-Criteria Decision Analysis (MCDA) produced the final landfill site suitability map. The final suitability map classified the study area into four categories, namely Highly Suitable, Moderately Suitable, Less Suitable, and Unsuitable. The highly suitable zones are primarily located on barren land in the peripheral parts of the municipality where road accessibility is adequate and environmental constraints are minimal. These locations are sufficiently distant from residential areas, water bodies, agricultural land, and other environmentally sensitive features, making them technically feasible and environmentally sustainable for future landfill development.

The existing dumping site was found to fall within the less suitable category due to its proximity to environmentally sensitive features. In contrast, the proposed landfill locations satisfy most of the environmental and planning criteria recommended under the Solid Waste Management Rules (2016), indicating their greater suitability for sustainable municipal solid waste management.

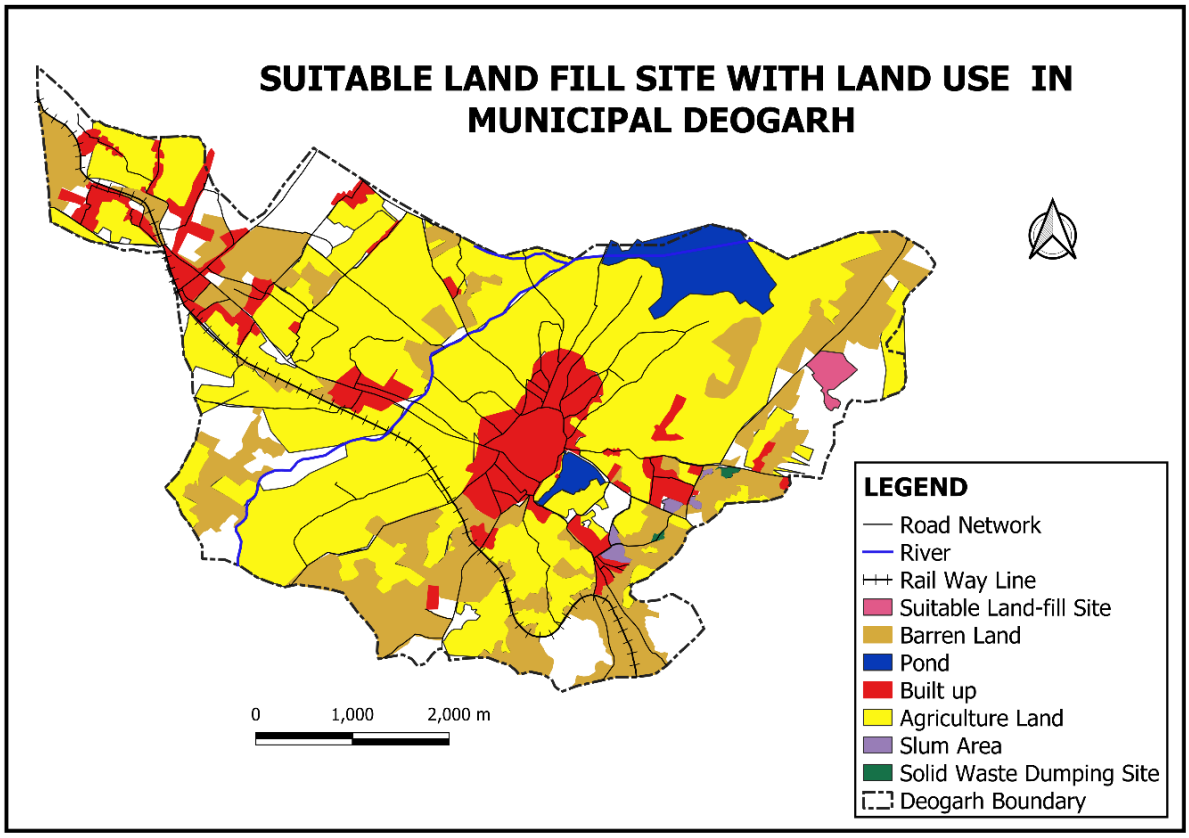

Figure 8: Final Landfill Site Suitability Map

5. DISCUSSION

The present study demonstrates that the integration of Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA) provides an effective, transparent, and scientifically reliable approach for landfill site suitability assessment in the Deogarh Municipal Area. By integrating multiple environmental and socio-economic criteria, including land use/land cover, road network, water bodies, railway lines, built-up areas, agricultural land, and slope, the study successfully identified environmentally suitable locations for future landfill development. The GIS-based approach minimized subjective decision-making and enabled systematic evaluation of spatial parameters, thereby improving the reliability of landfill site selection.

The results revealed that the existing municipal dumping site, despite having good road accessibility, does not fully satisfy the environmental criteria recommended under the Solid Waste Management Rules (2016) and the Central Pollution Control Board (CPCB) guidelines. The close proximity of residential settlements, agricultural land, educational institutions, and water resources increases the potential risk of groundwater contamination, soil

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degradation, air pollution, odour nuisance, and public health problems. These findings indicate that continued use of the existing dumping site may create long-term environmental and socio-economic challenges unless proper scientific landfill management practices are adopted. The proposed landfill sites identified through GIS-MCDA are environmentally more suitable because they are primarily located on barren land with gentle slopes, lower population density, adequate road accessibility, and safe distances from residential areas, water bodies, agricultural land, and other environmentally sensitive features. Such locations are expected to reduce environmental risks while improving the operational efficiency of municipal solid waste management. The suitability of these sites demonstrates the importance of integrating multiple spatial criteria rather than relying solely on land availability for landfill site selection. The findings of the present study are consistent with previous research conducted in different parts of the world. Chang et al. (2008) reported that GIS integrated with multi-criteria decision-making significantly improves the scientific accuracy of landfill site selection by combining multiple environmental parameters. Similarly, Nas et al. (2010) concluded that buffer analysis around environmentally sensitive features is essential for minimizing environmental risks associated with landfill development. Ali et al. (2021) further emphasized that GIS-based MCDA provides reliable decision support for municipal waste management planning, while Rane et al. (2024) demonstrated that integrated spatial analysis enhances the environmental sustainability of landfill site selection. The findings of the present study are therefore in agreement with these earlier studies, confirming the effectiveness of GIS-based spatial decision-support systems for sustainable landfill planning. From an environmental perspective, the study highlights that scientifically selected landfill sites can substantially reduce groundwater pollution, soil contamination, surface water degradation, and air pollution caused by uncontrolled waste disposal. Establishment of landfill facilities in environmentally suitable locations also contributes to biodiversity conservation, protection of agricultural land, and improvement of overall urban environmental quality. These outcomes support the principles of sustainable environmental management and responsible urban planning. The present study also has significant practical implications for municipal authorities and urban planners. The GIS-based landfill suitability map developed in this research can serve as an effective decision-support tool for selecting future landfill sites, preparing municipal development plans, and implementing the Solid Waste Management Rules (2016). The proposed methodology may also reduce planning time, improve transparency in site selection, and minimize conflicts associated with land acquisition and environmental clearance. Despite its usefulness, the present study has certain limitations. The analysis was based on selected spatial criteria, whereas additional factors such as groundwater depth, soil permeability, geological characteristics, rainfall intensity, land value, population density, and future urban expansion were not incorporated due to limitations in data availability. Furthermore, equal or predefined weights were used in the MCDA process; future studies may apply advanced weighting techniques such as the Analytical Hierarchy Process (AHP), Fuzzy-AHP, or machine learning approaches to improve decision accuracy.

Future research may integrate high-resolution satellite imagery, drone-based surveys, real-time environmental monitoring, and artificial intelligence-based spatial modelling for more accurate landfill suitability assessment. In addition, future studies may evaluate future municipal waste generation scenarios and climate change impacts to support long-term sustainable waste management planning.

Overall, the present study provides a scientifically sound and practically applicable framework for landfill site suitability assessment in the Deogarh Municipal Area. The developed GIS-MCDA methodology can be replicated in other municipalities of Rajasthan and similar semi-arid regions of India, thereby contributing to environmentally sustainable municipal solid waste management and evidence-based urban planning.

6. CONCLUSION

The present study demonstrated the effectiveness of Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA) in identifying environmentally suitable landfill sites within the Deogarh Municipal Area. The integration of multiple spatial criteria, including land use/land cover, road network, water bodies, built-up areas, agricultural land, railway lines, and slope, provided a scientific and reliable framework for landfill site suitability assessment.

The findings revealed that the existing municipal solid waste disposal site, although well connected by the road network, is located in close proximity to residential areas, agricultural land, and public institutions. This increases the potential risk of groundwater contamination, soil degradation, air pollution, odour nuisance, and adverse impacts on public health. Consequently, the existing site does not fully satisfy the environmental and planning criteria required for sustainable landfill development.

The GIS-based suitability analysis identified alternative locations that are environmentally and technically more appropriate for future landfill development. The most suitable sites are located on barren land at the outskirts of the municipality, away from residential areas, water bodies, and environmentally sensitive zones, while maintaining good

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road accessibility. These locations are characterised by gentle slopes, low flood risk, and sufficient land availability, making them suitable for long-term municipal solid waste disposal.

The study further recommends that future landfill development should comply with the Solid Waste Management Rules, 2016, and the guidelines of the Central Pollution Control Board (CPCB). Scientific landfill design, source segregation of waste, leachate collection and treatment, landfill gas management, environmental monitoring, and the establishment of green buffer zones should be adopted to minimise environmental impacts and safeguard public health.

This study provides the first GIS-MCDA-based landfill suitability assessment for the Deogarh Municipal Area and offers a replicable framework for similar municipalities in Rajasthan.

Municipal Council should incorporate the identified suitable sites into future waste management plans. The findings can support evidence-based implementation of the Solid Waste Management Rules, 2016.

Overall, the study confirms that GIS-based MCDA is a practical, accurate, and cost-effective decision-support tool for landfill site selection. The proposed methodology can assist municipal authorities, planners, and policymakers in developing sustainable solid waste management strategies and can also be applied to other urban areas facing similar waste management challenges.

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