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Research Article

Optimizing Landfill Siting in Pokhara Metropolitan City Using Gis-based Multi-criteria Decision Analysis

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Abstract

Pokhara Metropolitan City has seen a rapid expansion of the urban footprint, and population growth has resulted in an increase in municipal solid waste that far exceeds the capacity for disposal and management. This study utilized a GIS-based Multi-Criteria Decision Analysis (MCDA) approach using the Analytic Hierarchy Process (AHP) to determine the best locations for landfill sites. The study selected eight criteria and assigned weights to the criteria based on the relative importance to determine landfill suitability: proximity to lakes, rivers, roads, and settlements, slope, soil type, land use/land cover (LULC) type, and tourism areas. An assigning weight and combining analysis was performed in ArcGIS in which spatial layers were reclassified for analysis using weighted overlay analysis. The final product was a suitable map of land represented in four classes: unsuitable, less suitable, suitable, and highly suitable. The study results demonstrate that only 5.2% of the total area is very suitable for landfill development and that the highest consolidated amounts of land designated as highly suitable were in the north and east wards. Field verification showed that the GIS-based model is reliable, and the process is transparent and replicable. The methodology used in this study is important for sustainable landfill siting in urban planning, and the method has wider applications for similar areas in the Himalaya region undergoing rapid urbanization.

Keywords

GIS, MCDA, Landfill Siting, AHP, Waste Management, Environmental Impact, Spatial Analysis, Urban Planning

1. Introduction

1.1. Background

The rapid pace of urbanization and population growth in many developing cities, including Pokhara Metropolitan City, has led to an increasing demand for effective solid waste management systems. One of the most critical components of this system is the identification of environmentally, socially, and technically suitable sites for waste disposal. Poorly selected landfill sites can result in numerous adverse consequences, such as groundwater contamination, air pollution, land degradation, and negative impacts on public health and tourism.

Traditional methods of site selection, which often rely on limited field surveys or political decisions, are inadequate for addressing the multidimensional nature of the problem. A more comprehensive and spatially informed approach is necessary—one that incorporates a variety of environmental and infrastructural factors. In this context, Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA) have emerged as powerful tools, enabling planners

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and decision-makers to integrate, analyze, and visualize complex spatial data from multiple sources.

This study focuses on applying GIS techniques in combination with weighted overlay analysis to evaluate multiple thematic criteria including proximity to roads, rivers, lakes, settlements, slope gradient, soil type, land use/land cover (LULC), and tourism areas. These criteria were selected due to their direct or indirect influence on landfill suitability in terms of environmental safety, operational efficiency, and socio-economic acceptability.

By developing and overlaying individual suitability layers, this research aims to identify the most appropriate locations for landfill development in Pokhara Metropolitan City. The integration of remotely sensed data, digital environment maps, and spatial analysis ensures a more accurate, transparent, and scientifically defensible site selection process.

1.2. Problem Statement

Effective solid waste management remains one of the most pressing urban challenges in developing cities today. Despite advancements in recycling, composting, and waste minimization, complete elimination of municipal solid waste is not feasible, making landfill siting an inevitable and essential component of urban waste management systems. The issue becomes more critical in rapidly growing urban centers like Pokhara Metropolitan City, where the generation of municipal solid waste has surpassed the capacity for safe and efficient disposal.

Currently, over 200 tons of solid waste are generated daily, while the city's waste management system can handle only around 90 tons, creating a severe shortfall in disposal capacity. The practice of dumping waste in unsuitable areas, such as along riverbanks and close to residential settlements, has resulted in environmental degradation, including river and land pollution, unpleasant odors, and heightened public health risks due to the spread of vector-borne diseases.

This situation is further aggravated by factors such as rapid urban expansion, limited availability of suitable land, and the lack of integrated planning that incorporates key biophysical and socio-economic considerations. Currently, landfill site selection processes are not guided by a standardized or scientific methodology, and critical factors like proximity to water bodies, settlements, roads, land use, slope, soil type, and ecological sensitivity are often neglected or poorly weighted.

Given this context, there is a clear and urgent need for a systematic, GIS-based multi-criteria decision-making approach to identify environmentally and technically suitable locations for landfill development. This study aims to fill this gap by developing a spatial decision support framework that integrates diverse thematic layers to guide sustainable waste disposal planning in Pokhara Metropolitan City.

1.3. Objectives

The primary objective of this study is to apply Geographic Information System-based Multi-Criteria Decision Analysis (GIS-MCDA) to identify suitable landfill sites in Pokhara Metropolitan City.

The secondary objectives are:

Evaluate key criteria for landfill siting, including proximity to water bodies, settlements, roads, slope, and land use/land cover.

Develop suitability maps using weighted overlay analysis to classify areas as Restricted unsuitable, less suitable, suitable, and highly suitable.

Validate the suitability analysis through field verification in person and alignment with government regulations to ensure practical applicability.

1.4. Significance

This study holds significant relevance for Pokhara Metropolitan City, where improper waste disposal practices have led to environmental degradation and public health risks. By applying GIS-based Multi-Criteria Decision Analysis (GIS-MCDA) to identify suitable landfill sites, this research provides a practical and scientifically grounded solution to address the city's waste management crisis, particularly in the context of its limited land availability, rapid urbanization, and ecological sensitivity. The suitability maps generated offer local authorities a clear framework for decision-making, ensuring minimal impact on water bodies, settlements, and agricultural lands while improving the quality of life for residents through reduced pollution and health hazards.

Beyond Pokhara, the methodology and findings have broader applications in urban planning, particularly for other Himalayan cities facing similar challenges of population growth and constrained geography. The integration of GIS-MCDA establishes a replicable model that can be adapted to diverse urban contexts, supporting sustainable waste management practices and policy development. This study also contributes to the global discourse on environmentally conscious urban planning by demonstrating how spatial analysis can balance development needs with ecological preservation, offering a blueprint for municipalities aiming to achieve long-term sustainability in waste management.

2. Literature Review

The management of municipal solid waste has emerged as a critical global challenge, driven by rapid urbanization, population growth, and changing consumption patterns. Improper site selection for waste disposal exacerbates environmental degradation, economic losses, and public health risks, necessitating advanced methodologies for sustainable solutions. Geographic Information Systems (GIS) integrated with Multi-Criteria Decision Analysis (MCDA), particularly the Analytic Hierarchy Process (AHP), have been widely recognized as effective tools for landfill site selection, as evidenced by numerous studies across diverse regions.

A study in Kathmandu Valley, Nepal, utilized Quantum GIS (QGIS) and AHP to assess suitable waste disposal sites, considering eight criteria including distance to water bodies, roads, settlements, slope, soil type, geology, land cover, and protected areas. The results highlighted the inadequacy of intra-valley sites, with only 1% of the area deemed suitable, suggesting the need for external disposal locations [1]. Similarly, a study in Pokhara Metropolitan City found that 11,574,285 m^2 (2.24%) of the area was extremely unsuitable, while 632,115 m^2 (0.26%) was highly suitable for waste disposal, identifying four optimal sites in the southern part of the city [2].

In Istanbul, Turkey, GIS and AHP were applied using 11 environmental and economic criteria, such as land use, population density, and highways, identifying 2% of the area as highly suitable near Silivri district [3]. Studies in India emphasized minimizing environmental impacts through GIS-based decision systems, with one study developing a suitability index incorporating geology, groundwater depth, and land use [4]. Another study in Guwahati, India, used GIS-MCDA-AHP with seven criteria, highlighting challenges in low- and middle-income cities [5]. In Pakistan, a study in Jacobabad integrated Remote Sensing (RS) with GIS, considering social and technical factors, and recommended further geotechnical analysis [6].

In Nepal, research in Achham District [7] and Dadeldhura [8] used GIS and MCDA to identify suitable landfill sites, focusing on criteria like proximity to rivers, roads, and settlements, with the latter identifying 3.22% of the area as highly suitable. A study in Banepa integrated AHP and network analysis, reducing travel distance by 33% and costs by 24%, showcasing broader benefits for waste management sustainability [9]. Additional studies in Thiruvallur, India [10], and Sicily, Italy [11], validated the efficacy of QGIS and AHP in producing suitability maps, categorizing areas based on factors like land cover and proximity to infrastructure. Another study in Lucknow, India, integrated RS with GIS-AHP, demonstrating the utility of multi-criteria layers for thematic mapping [12]. A study in Butwal Sub-Metropolitan City, Nepal, applied GIS and MCDA to select landfill sites, emphasizing the importance of spatial analysis in urban planning [13]. Collectively, these studies affirm that GIS-MCDA, particularly with AHP, provides a robust, replicable framework for landfill siting, addressing environmental risks and supporting urban planning, though limitations such as reliance on secondary data and the need for field validation persist [1-13].

3. Study Area

The study area for this project is Pokhara Metropolitan City, selected to determine suitable sites for waste disposal. Pokhara Metropolitan City is located in the mid-hill region of western Nepal and is characterized by diverse and dynamic natural conditions. It is surrounded by prominent mountain ranges, including the Annapurna and Machhapuchhre massifs. Located between latitudes 28°05′ N and 28°21′ N and longitudes 83°48′ E and 84°09′ E, it is the largest metropolis in Nepal, covering an area of 464.24 square kilometers. The elevation ranges from 827 meters to 1,740 meters above sea level, presenting diverse topographical challenges. Pokhara experiences a humid subtropical climate with high annual rainfall. The area is drained by several rivers and streams, notably the Seti River, which has deeply incised gorges within the valley. The presence of lakes such as Phewa, Begnas, and Rupa, along with fertile alluvial soils, contributes to the city's rich natural environment. This urban and tourist-heavy region generates significant waste, necessitating effective management solutions, which the study addresses using GIS and Multicriteria Decision Analysis (MCDA).

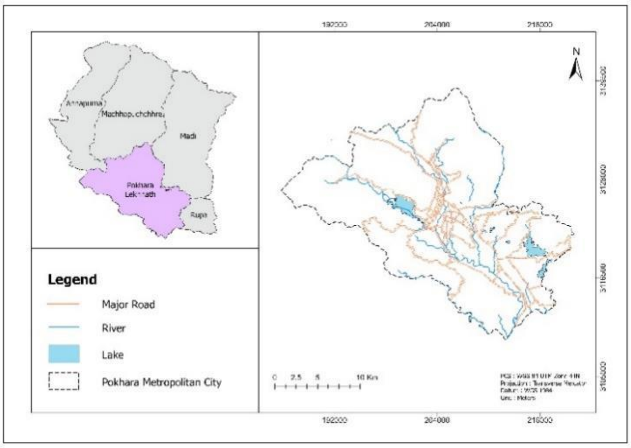


Figure 1. Map of the study area: Pokhara Metropolitan City - Nepal.

(Source: The map was prepared by the researcher, based on the data available from Department of Survey and Open Street Map)

4. Materials and Methods

4.1. Dataset Used

The research utilized a diverse set of geospatial data sources to ensure comprehensive analysis and robust findings. Soil data were obtained from the International Soil Reference and Information Centre (ISRIC) (http://www.isric.org), providing detailed soil properties critical for environmental and agricultural assessments. Lake, road, river, settlement, and tourism data were sourced from the Humanitarian OpenStreetMap Team (HOTOSM) Exports, offering high-resolution, community-driven datasets that capture water bodies, transportation networks, hydrological features, human settlements, and tourism-related points of interest, respectively. Slope data were derived from the ASTER Global Digital Elevation Model provided by the United States Geological Survey (USGS), enabling terrain analysis and topographic characterization. Land Use and Land Cover (LULC) data were acquired from the International Centre for Integrated Mountain Development (ICIMOD), offering insights into land use patterns and ecosystem dynamics. Together, these datasets provided a multidimensional foundation for the study, ensuring accuracy and relevance in the geospatial analysis conducted.

4.2. Software Used

ArcGIS Pro 3.6.0 Software and Online AHP Calculator (AHP Calculator - AHP-OS, n.d.) was used for mapping and analysis procedure.

4.3. Criteria Selection

1. Environmental Factors

These criteria focus on minimizing environmental impact, protecting ecosystems, and ensuring compliance with environmental regulations.

Lake (Proximity to Water Bodies): The proximity of a landfill to lakes and other surface water bodies must be carefully evaluated to avoid environmental pollution. Landfills located near lakes risk leachate leakage into these water bodies, potentially contaminating drinking water sources and harming aquatic ecosystems. To protect water quality, landfills should be situated far from lakes, with proper buffer zones established as per environmental regulations.

River (Proximity to Water Bodies): Similar to lakes, rivers are sensitive ecological features that must be protected from landfill-related contamination. Rivers are often used for drinking water, irrigation, and supporting biodiversity. If a landfill is sited too close to a river, it increases the risk of leachate entering the watercourse, particularly during flooding or heavy rainfall. Therefore, landfill sites should maintain a safe distance from rivers to minimize environmental and public health risks.

Slope: The slope of the land influences the landfill’s structural stability and drainage. Flat areas may have poor drainage, leading to water accumulation, while steep slopes can cause erosion or landslides. A moderate slope is typically ideal, as it supports natural runoff without causing soil erosion or instability. Proper slope selection also reduces the need for extensive engineering work during landfill construction.

Land Use and Land Cover (LULC): LULC analysis helps determine the existing use and ecological value of land. Landfills should avoid areas with agricultural use, forests, wetlands, urban zones, or protected land due to their economic, social, and ecological importance. Instead, barren lands or areas with minimal ecological or economic value are most suitable. Integrating LULC data ensures that the selected site causes the least disruption to the environment and human activities.

Geological Composition: Soil type is a critical factor in landfill site selection because it influences the rate at which leachate (contaminated liquid) can seep into the ground. Impermeable soils, such as clay, are ideal because they significantly reduce the risk of groundwater contamination. In contrast, sandy or porous soils allow fluids to percolate easily, which can pollute underground water sources. Therefore, sites with compact and stable soil types are preferred to naturally contain waste and reduce the need for engineered barriers.

2. Socio-Economic/Technical Factors

These criteria address social acceptability, economic feasibility, and technical suitability for landfill operations.

Settlement (Distance from Residential Areas): Landfills should be located away from human settlements to reduce negative impacts on public health and quality of life. Waste disposal sites generate odor, attract pests, increase vehicle traffic, and may cause noise pollution. In addition, landfills may reduce property values and create a stigma in nearby communities. Hence, maintaining a significant buffer distance from residential areas is essential for social acceptability.

Road (Accessibility): Road access is essential for transporting waste to the landfill site. A landfill should be located near existing road networks to ensure cost-effective and efficient waste transportation. However, it should not be too close to major highways or densely traveled routes to avoid creating traffic congestion, noise, dust, and odor-related complaints. Therefore, it is important to strike a balance between distance from residential areas, lakes, and rivers and proximity to the road network.

Tourism: Tourism areas are highly sensitive to environmental degradation and visual pollution. A landfill near a tourist site can harm the area's natural beauty, discourage visitors, and negatively affect the local economy. The unpleasant sight and smell of a landfill can ruin the tourist experience. Therefore, landfill sites must be located far from cultural, historical, and natural tourist attractions to preserve the area's image and economy.

Table 1. *Sources and types of digital data used in optimizing landfill siting in Pokhara Metropolitan City.*

Factors	Type	Source
Soil	Raster	http://www.isric.org
Lake	Vector	HOTOSM Export
Road	Vector	HOTOSM Export
River	Vector	HOTOSM Export
Slope	Raster	ASTER Global Digital Elevation Model-USGS
Settlement	Vector	HOTOSM Export
Tourism	Vector	HOTOSM Export
LULC	Raster	ICIMOD

4.4. GIS-MCDA Framework

The study employed the Analytical Hierarchy Process

(AHP), a widely recognized Multi-Criteria Decision Making (MCDM) tool, to integrate multiple factors and assign weights to criteria for suitability analysis. AHP facilitates the prioritization of alternatives by synthesizing multidimensional measures into a single scale of priorities [11]. Pairwise comparisons were conducted using a nine-point scale, ranging from 9 (extreme preference) to 1/9 (extreme non-preference), with intermediate values such as 7 (very strong preference), 5 (strong preference), and 1 (no preference). Preference data were gathered from relevant literature aligned with the hierarchical structure of the criteria. This pairwise comparison approach simplified the evaluation by assessing the independent contribution of each criterion relative to others, organized into a square matrix. The principal eigenvalue and corresponding eigenvector were calculated to determine the relative importance of each criterion within the comparison matrix. Weights for each criterion were derived from the normalized eigenvector. To ensure the reliability of subjective judgments, the consistency of the AHP model was evaluated using the Consistency Index (CI), calculated as:

$$CI = (\lambda max - n) \ / \ (n - 1) \quad (1)$$

Where λ max is the principal eigenvalue and (n) is the number of criteria. The Consistency Ratio (CR) was then computed by dividing CI by the Random Index (RI), with a threshold of CR ≤ 0.1 indicating acceptable consistency [11].

Recognizing that expert judgments may vary in pairwise comparisons, the final step involved assigning weights to each factor and aggregating them to derive a global suitability rating. A rating scale of 1 to 5 was used, where 1 represents restricted, 2 not suitable, 3 less suitable, 4 suitable and 5 highly suitable.

Pairwise Comparison Matrix (A) as:

Table 2. *Pairwise Camparison matrix.*

Factors	**Soil**	**Lake**	**Road**	**River**	**Slope**	**Settle**	**Tourism**	**LULC**
Soil	1	1/5	1/2	1/4	2	1/5	1/2	2
Lake	5	1	3	1	3	4	3	5
Road	2	1/3	1	1/3	2	1/3	1	2
River	4	1	3	1	3	4	2	4
Slope	1/2	1/3	1/2	1/3	1	1/3	1	2
Settle	5	1/4	3	1/4	3	1	3	4
Tourism	2	1/3	1	1/2	1	1/3	1	2
LULC	1/2	1/5	1/2	1/4	1/2	1/4	1/2	1

Table 3. *Weights of factors used in optimizing landfill siting in Pokhara Metropolitan City.*

Factors	**Weight (%)**
Soils	5.7
Lake	26.1
Road	8.7
River	23.9
Slope	6.5
Settlement	16.9
Tourism	8.4
LULC	3.8

The weights were derived from the pairwise comparison matrix using Saaty's method (1977), where comparisons are analyzed and normalized to produce weights that sum to 100 percent.

Additionally, the consistency of the pairwise comparisons was evaluated by calculating the Consistency Ratio (CR) to ensure the reliability of the judgments.

$$\text{Consistency Ratio} = \text{Consistency Index (CI)} / \text{Random Index (RI)} \quad (2)$$

The Consistency Index (CI) is calculated using the formula (1):

The Random Index (RI), used for consistency checking, varies based on the number of elements being compared.

From above matrix, $\lambda max \approx 8.45$

For n=8:

$CI = 8.45 - 8/7 = 0.064$

The Random Index (RI) for n=8 is 1.41.

$CR = CI/RI = 0.064/1.41 = 0.045$

Since $CR < 0.10$, the matrix is consistent.

4.5. Digital Environment Maps and GIS Analysis

Geographic Information Systems (GIS) play a vital role in handling and interpreting complex spatial datasets, making them indispensable in informed decision-making processes such as landfill site selection. In this study, GIS tools within the ArcGIS platform were employed to develop several spatial models aimed at identifying suitable areas for waste disposal in Pokhara Metropolitan City. These models facilitated the integration, analysis, and visualization of diverse geospatial criteria critical to the site selection process.

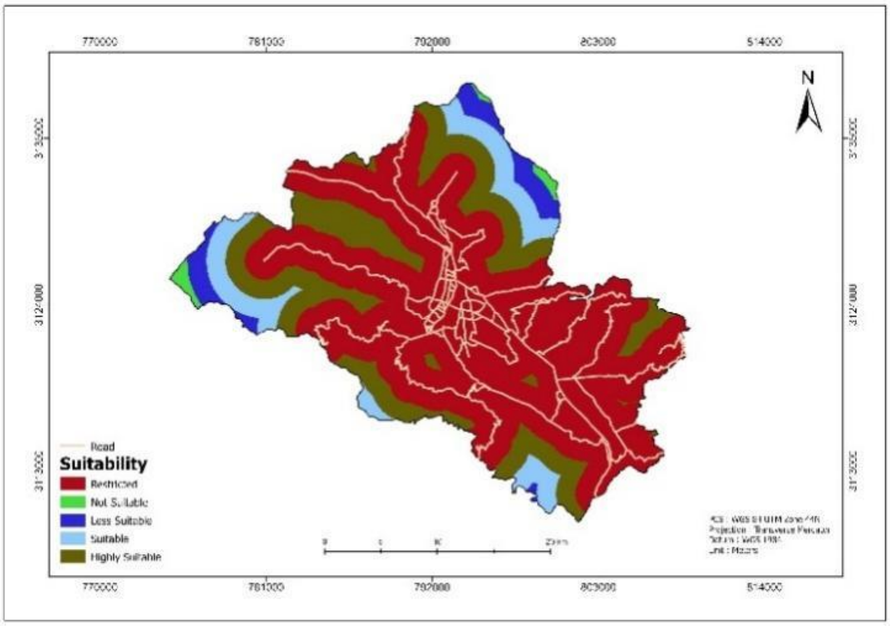
i) Thematic Suitability Layers

To standardize each factor on a common scale (1-5), individual thematic layers were developed for each criterion. The Euclidean Distance tool was applied to calculate proximity to features such as roads, rivers, lakes, and settlements within the study boundary. These distance-based layers were then reclassified using the Reclassify tool under Spatial Analyst, assigning values where:

1= Restricted areas

5 = Most suitable areas

Road Suitability Layer: The Road Suitability Layer illustrates areas based on their distance from the road network, influencing the feasibility of waste disposal site selection. Areas closest to roads (shown in brown and light blue) are considered highly suitable due to ease of access and lower transportation costs. As the distance increases (blue to green), suitability decreases, and the farthest zones (red) are marked as restricted due to logistical challenges. This layer helps identify locations that balance accessibility and operational efficiency for waste management.



(Source: The map was prepared by the researcher, based on the data available from Open Street Map)

Figure 2. *Suitability of distances from roads to optimize landfill siting in Pokhara Metropolitan City, Nepal as of July 2025.*

River Suitability Layers: The River Suitability Layer categorizes areas based on their proximity to rivers, aiming to minimize the risk of water contamination from landfill runoff. Zones closest to rivers (shown in red) are marked as restricted, while areas gradually farther away transition from not suitable (green), less suitable (blue), and suitable (light blue), to highly suitable (brown). This spatial distribution ensures that waste disposal sites are located at safe distances, reducing environmental hazards and protecting aquatic ecosystems.

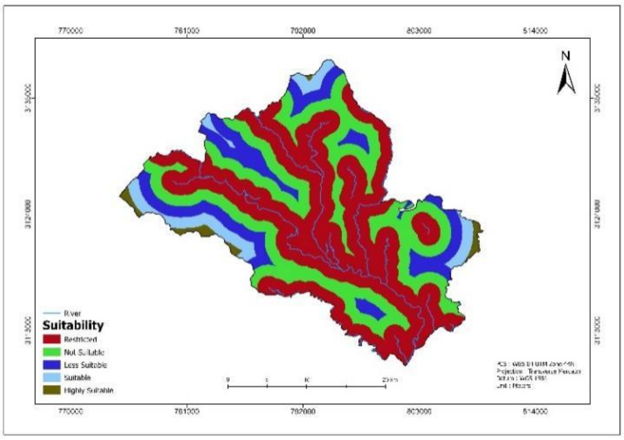


Figure 3. *Suitability of distances from rivers to optimize landfill siting in Pokhara Metropolitan City, Nepal as of July 2025.*

(Source: The map was prepared by the researcher, based on the data available from Open Street Map)

Lake Suitability Layers: The Lake Suitability Layer classifies areas according to their distance from lakes, with the aim of preventing leachate pollution and protecting freshwater ecosystems. Areas immediately surrounding lakes (in red) are marked as restricted, while zones farther out are progressively labeled not suitable (green), less suitable (blue), suitable (light blue), and highly suitable (brown). This gradation helps ensure that waste disposal sites are placed at environmentally safe distances from lakes, aligning with hydrological safety and sustainability principles.

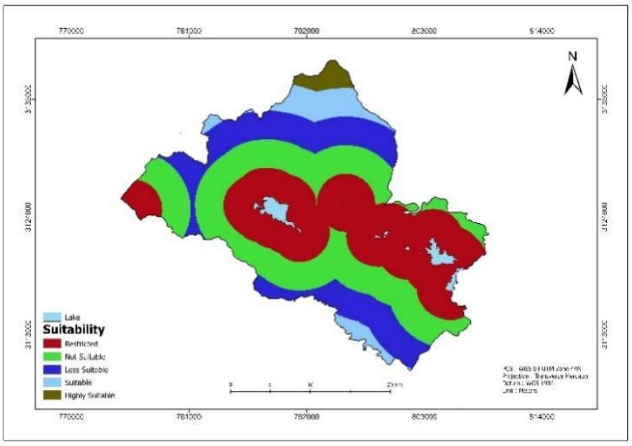
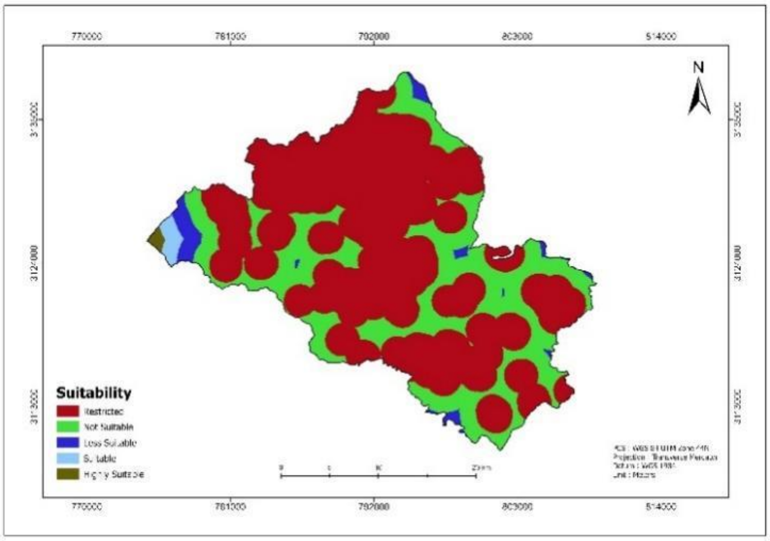


Figure 4. *Suitability of distances from lakes to optimize landfill siting in Pokhara Metropolitan City, Nepal as of July 2025.*

(Source: The map was prepared by the researcher, based on the data available from Open Street Map)

Settlement Buffer Layer: The Settlement Suitability Layer classifies areas based on their distance from residential zones, aiming to minimize health risks, odors, and social opposition associated with landfill sites. Areas immediately adjacent to settlements (in red) are marked as restricted, indicating they are unsuitable for landfill placement due to proximity to human populations. Zones farther out are progressively labeled unsuitable (green), less suitable (blue), suitable (light blue), and highly suitable (brown), reflecting increasing distances that reduce environmental and social impacts. This gradation ensures that waste disposal sites are located at safe distances from settlements, aligning with public health, social acceptability, and sustainability principles in the context of Pokhara Metropolitan City.



(Source: The map was prepared by the researcher, based on the data available from Open Street Map)

Figure 5. *Suitability of buffer from settlements to optimize landfill siting in Pokhara Metropolitan City, Nepal as of July 2025.*

Slope Evaluation Layer: The Slope Suitability Layer classifies areas based on their slope gradient, aiming to ensure structural stability, proper drainage, and minimal erosion risk for landfill sites. Areas with steep slopes (in red) are marked as restricted, indicating they are unsuitable due to the risk of landslides or erosion, particularly relevant in Pokhara's hilly terrain. Zones with moderate to steep gradients (green) are labeled not suitable, while areas with gentler slopes (blue) are progressively classified as less suitable, suitable, and highly suitable (brown), reflecting increasing stability and drainage potential. This gradation ensures that waste disposal sites are located on slopes that support safe construction and operation, aligning with geotechnical safety and sustainability principles in the context of Pokhara Metropolitan City.

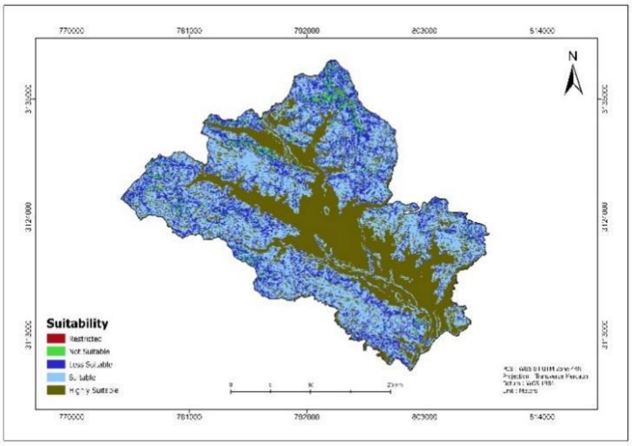


Figure 6. Suitability of slope Evaluation to optimize landfill siting in Pokhara Metropolitan City, Nepal as of July 2025.

(Source: The map was prepared by the researcher, based on the DEM data available from opentopography)

Land Use and Land cover Classification Layer: The LULC (Land Use and Land Cover) Suitability Layer classifies areas based on their existing land use and ecological value, aiming to minimize disruption to human activities and natural ecosystems for landfill siting. Areas designated as restricted (in red) include urban zones, agricultural lands, forests, wetlands, or protected areas, indicating they are unsuitable due to their economic, social, and ecological importance. Zones with less suitable land use (green) are labeled unsuitable, while areas with moderate ecological value (blue) are classified as less suitable, and regions with barren or degraded land (light blue) are progressively labeled suitable and highly suitable (brown). This gradation ensures that waste disposal sites are located on land with minimal ecological or economic value, aligning with environmental sustainability and land-use planning principles in the context of Pokhara Metropolitan City.

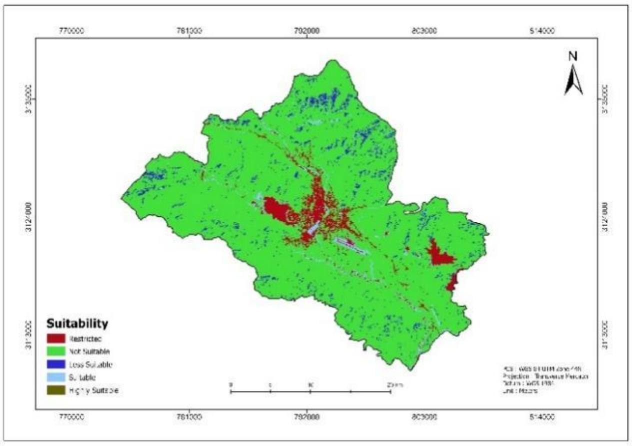


Figure 7. Suitability of Land Use and Land cover Classification to optimize landfill siting in Pokhara Metropolitan City, Nepal as of July 2025.

(Source: The map was prepared by the researcher, based on the landsat satellite imagery available from USGS earth explorer)

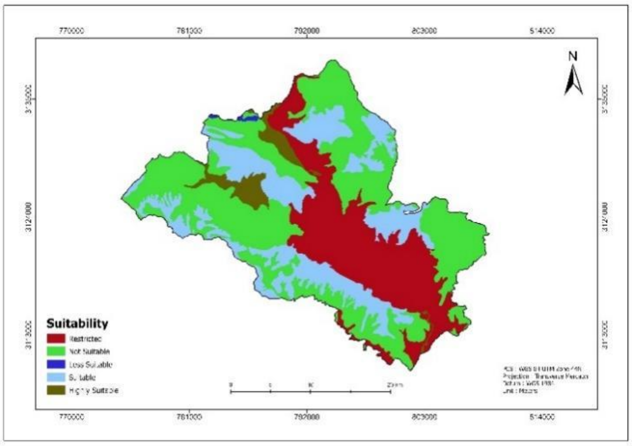
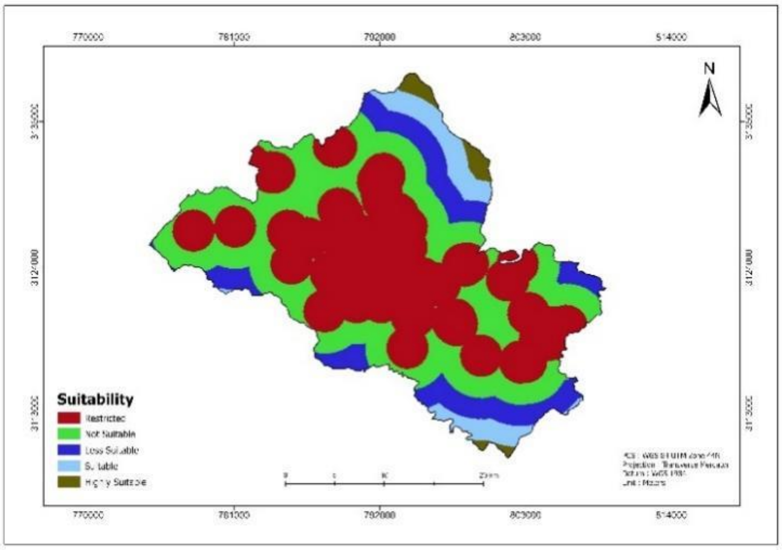


Figure 8. Suitability of Soil Type to optimize landfill siting in Pokhara Metropolitan City, Nepal as of July 2025.

(Source: The map was prepared by the researcher, based on the data available from National Agriculture Research Council)

Soil Type Suitability Layer: The Soil Suitability Layer classifies areas based on soil type and permeability, aiming to minimize the risk of leachate contamination and ensure stable landfill siting. Areas with highly permeable soils (in red) are marked as restricted, indicating they are unsuitable due to the risk of groundwater pollution from leachate seepage. Zones with moderately permeable soils (green) are labeled not suitable, while areas with less permeable soils (blue) are classified as less suitable, and regions with impermeable soils like clay (light blue) are progressively labeled suitable and highly suitable (brown). This gradation ensures that waste disposal sites are located on soils that naturally contain leachate, aligning with groundwater protection and geotechnical stability principles in the context of Pokhara Metropolitan City.

Tourism Impact Layer: The Tourism Suitability Layer classifies areas based on their proximity to tourist attractions, aiming to preserve the natural beauty, cultural value, and economic benefits of tourism for landfill siting. Areas immediately adjacent to tourism sites (in red) are marked as restricted, indicating they are unsuitable due to the risk of visual pollution, odor, and economic loss. Zones farther out (green) are labeled not suitable, while areas with increasing distance (blue) are classified as less suitable, and regions progressively farther (light blue) are labeled suitable and highly suitable (brown), reflecting reduced impact on tourist experiences. This gradation ensures that waste disposal sites are located at safe distances from cultural, historical, and natural attractions, aligning with tourism preservation and economic sustainability principles in the context of Pokhara Metropolitan City.



(Source: The map was prepared by the researcher, based on the data available from Open Street Map)

Figure 9. *Suitability of Tourism Impact to optimize landfill siting in Pokhara Metropolitan City, Nepal as of July 2025.*

ii) Composite Suitability Map

Using the Weighted Overlay tool, all reclassified layers were combined to create a composite suitability map. Each factor was assigned a weight based on its relative influence, resulting in a continuous surface that classified the study area from restricted to highly suitable for landfill siting.

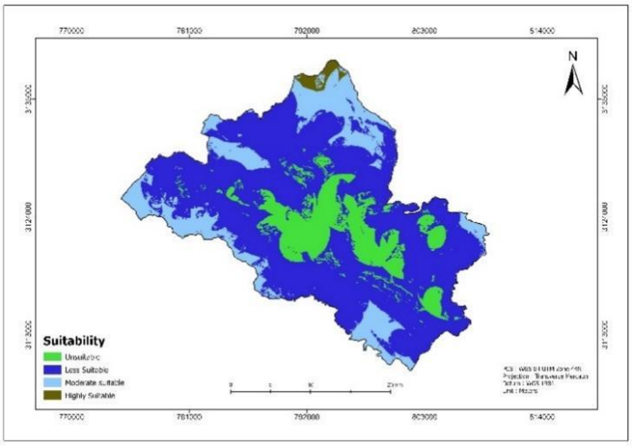


Figure 10. *Suitability Map.*

iii) Extracted Suitable Zones

The most appropriate zones for waste disposal were isolated using the ArcGIS Pro. This layer highlighted areas with optimal spatial characteristics for siting waste facilities.

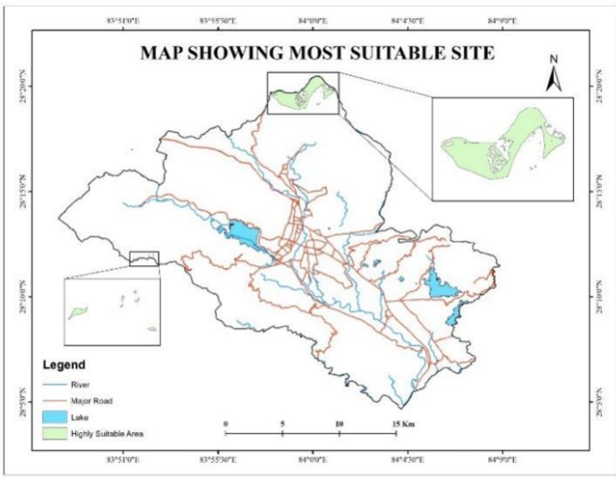


Figure 11. *Map showing Most Suitable Site.*

v) Field Verification

To validate the GIS-based suitability analysis, field verification was conducted in July 2025 at highly suitable sites in Pokhara Metropolitan City's northern and eastern wards (Figure 12). Using camera and GPS device, the team documented site characteristics like land cover, road access, slope, and proximity to settlements or water bodies. Photographs were captured to provide visual evidence of site conditions, such as barren land, absence of ecological features, or infrastructure suitability. The field observations were compared with the thematic suitability layers (Figures 2-9) to confirm the appropriateness of the selected sites.

Figure 12. Photograph from the field verification.

Figure 13. Photograph from the field verification.

Figure 14. Photograph from the field verification.

4.6. Workflow

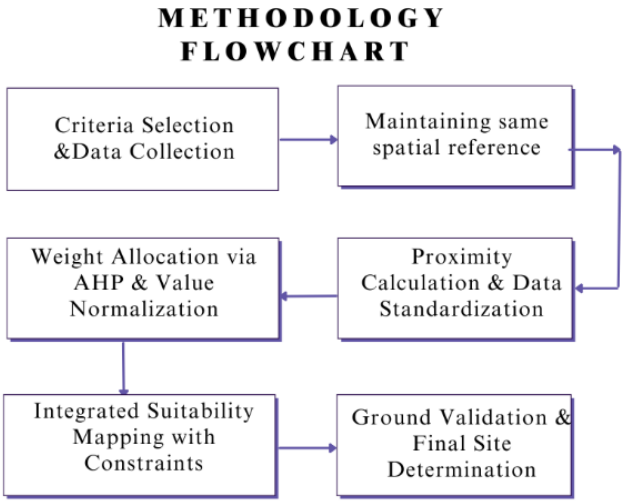


Figure 15. Methodology Flowchart.

5. Results

The GIS-based Multi-Criteria Decision Analysis (GIS-MCDA) approach successfully identified suitable landfill sites in Pokhara Metropolitan City by integrating eight thematic layers: proximity to lakes, rivers, roads, settlements, slope, soil type, land use/land cover (LULC), and tourism areas. Using the Analytic Hierarchy Process (AHP), weights were assigned to each criterion (Table 3). The Weighted Overlay tool in ArcGIS combined these reclassified layers to produce a composite suitability map (Figure 10), classifying the study area into four categories: unsuitable, less suitable, suitable, and highly suitable.

The results indicate that 67.5% of the total area (approximately 313.36 km²) is unsuitable for landfill siting, primarily due to proximity to water bodies, settlements, and ecologically sensitive zones such as forests and agricultural lands. Restricted areas, marked by regulatory or environmental constraints, account for an additional 15.3% (71.03 km²). Less suitable and suitable areas cover 12.0% (55.71 km²) and 5.2% (24.14 km²), respectively. Notably, 5.2% of the area (24.14 km²) was classified as highly suitable, predominantly located in the northern and eastern wards of Pokhara Metropolitan City, characterized by barren or degraded lands, impermeable soils, moderate slopes, and sufficient distance from settlements, water bodies, and tourism sites.

The composite suitability map (Figure 10) visually delineates these zones, highlighting clusters of highly suitable sites in wards with minimal socio-economic and environmental conflicts. The final extracted suitable zones map (Figure 11) pinpoints four primary sites, each exceeding 0.5 km², with optimal spatial characteristics for landfill development, including accessibility via existing road networks and low ecological value.

In the previous researches, field verification was lacking and they had used fewer criteria than ours, so they had allocated siting location on eastern part only. Our field verification in July 2025 confirmed the GIS-MCDA suitability of sites in Pokhara Metropolitan City's northern and eastern wards. The photograph taken (Figure 13) during the field verification of suggest that these observations aligned with the GIS layers (Figures 2-9).

These findings provide a spatially explicit framework for landfill site selection, addressing Pokhara's waste management crisis by identifying environmentally and technically viable locations. The results align with previous studies in similar contexts, such as Bhandari and Pokhrel (2020), which identified 0.26% of Pokhara's area as highly suitable, though this study's broader criteria set and updated data yield a larger proportion of suitable land.

6. Discussion

The GIS-based Multi-Criteria Decision Analysis (GIS-MCDA) identified 5.2% (24.14 km²) of Pokhara Metropolitan City as highly suitable for landfill siting, mainly in northern and eastern wards, using eight criteria weighted via the Analytic Hierarchy Process (AHP). These areas feature impermeable soils, moderate slopes, and minimal proximity to settlements, water bodies, and tourism sites, addressing Pokhara's waste management crisis (200 tons daily vs. 90-ton capacity). Compared to Bhandari and Pokhrel (2020), which found only 0.26% suitability, this study's broader criteria and updated data (ISRIC, HOTOSM, ICIMOD) yield a higher suitable area [2]. Similar studies in Kathmandu (1% suitable) and Istanbul (2%) highlight the scarcity of suitable land in urban settings [1, 4]. Field verification in July 2025 confirmed model reliability, but secondary data limitations and potential AHP bias persist, as noted in Guwahati's study [5]. The methodology's replicability suits other Himalayan cities, yet future research should include groundwater and climate impact criteria, as seen in Indian studies [4, 12], and geotechnical assessments [6] to enhance robustness and sustainability.

7. Conclusions

The GIS-based Multi-Criteria Decision Analysis (GIS-MCDA) effectively identified suitable landfill sites in Pokhara Metropolitan City, addressing its waste management crisis. Of the 464.24 km² area, 5.2% (24.14 km²) was highly suitable, mainly in northern and eastern wards, while 67.5% was unsuitable due to environmental and socio-economic constraints. Field verification in July 2025, supported by photographs (Figure 12), confirmed site suitability, enhancing result reliability. This study offers a transparent framework for sustainable landfill siting, applicable to other Himalayan cities. Despite limitations like secondary data reliance, it supports eco-friendly urban planning. Future research could explore climate impacts and geotechnical assessments.

Abbreviations

GIS	Geographic Information System
MCDA	Multi Criteria Decision Analysis
AHP	Analytic Hierarchy Process
LULC	Land Use/Land Cover
HOTOSM	Humanitarian OpenStreetMap Team
ISRIC	International Soil Reference and Information Centre
USGS	United States Geological Survey
ICIMOD	International Centre for Integrated Mountain Development
CI	Consistency Index
CR	Consistency Ratio
RI	Random Index

Supplementary Material

The supplementary material can be accessed at https://doi.org/10.11648/j.sdenv.20260101.18

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Author Contributions

Subash Rimal: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Writing – original draft.

Lav Gurung: Resources, Software, Validation, Visualization, Writing – review & editing.

Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

Subash Rimal is a Geomatics Engineering graduate from the Institute of Engineering (IOE), Pashchimanchal Campus, Pokhara, Nepal, where he earned his Bachelor's degree. Passionate about geospatial technologies, he is committed to advancing research in spatial analysis, remote sensing, and sustainable development. Subash has demonstrated leadership as a team member of Youth Action for Sustainable and Eco Nepal (YASEN) and led Team Ananta to victory in the On-Campus Hult Prize Idea Pitching Competition in 2024, qualifying for the regional round. Recognized for his technical and analytical skills, he is an open-minded team player with a strong foundation in GIS, UAV-based mapping, and participatory geospatial methods, aiming to make significant contributions to academia and innovative research.

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Research Field

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