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Optimal Site Selection for Construction Waste Disposal in Yazd City-Iran Using Multi-Criteria Decision Analysis (MCDA) and GIS Tools

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ABSTRACT

Background and objective: Construction waste management is a critical concern for urban development, particularly in rapidly growing cities like Yazd, where improper disposal poses significant environmental and health risks. Identifying suitable locations for construction waste landfills, while considering environmental, social, and logistical criteria, is essential for sustainable urban planning. This study aimed to use Geographical Information Systems (GIS) and the Analytical Hierarchy Process (AHP) to identify the most suitable sites for construction waste disposal in Yazd, based on key criteria such as proximity to population centers, water resources, and transportation networks.
Materials and methods: A comprehensive multi-criteria evaluation was conducted by integrating spatial data with expert opinions using GIS and AHP techniques. Several key factors, including proximity to population centers, water bodies, access networks, wind direction, and land use, were considered. A pair-wise comparison matrix was developed to assign relative weights to these factors based on their importance, and a suitability map was generated to identify the optimal landfill locations. The study area was then divided into different zones, categorized based on their level of suitability for waste disposal.
Results and conclusion: The final land suitability map identified three main sites, with Site 1 (44.39 hectares in the northeast) emerging as the most suitable location for a new landfill, given its favorable wind direction, distance from population centers, and stable land features. Site 2 (21.17 hectares) and Site 3 (20.6 hectares) were also identified as viable alternatives. The analysis of existing waste disposal sites revealed that the site near Azadegan Road has better suitability, while the Faqih Khorasani Boulevard site was deemed unsuitable. The results demonstrate the efficacy of GIS and AHP in facilitating informed decision-making for sustainable waste management in urban areas.

1. Introduction

The rapid growth of urban populations and the continuous increase in the production and disposal of waste into the environment have posed significant challenges to both human societies and the ecosystems surrounding them. Among the critical challenges of urbanization, managing construction

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waste has emerged as a pressing issue. Construction waste, whether generated by environmental hazards such as natural disasters (earthquakes, hurricanes, floods) or by human activities such as construction, renovation, repair, and demolition of urban structures, is a significant source of environmental pollution (Ugwuanyi & Isife, 2012).

The construction industry, as a major consumer of natural resources, is responsible for producing a considerable amount of waste. Studies have shown that the average life cycle of buildings globally is approximately 40 years. Given that around 25% of the world's urban fabric is classified as dilapidated, the increasing demand for new construction results in a dramatic rise in construction waste (Sharma et al., 2022). If not properly managed, this waste poses a significant threat to environmental sustainability. However, with the advancement of technology and increased awareness of environmental challenges, construction waste can be managed effectively through practices such as recycling and reuse, leading to a reduction in the consumption of raw materials and waste production. By converting waste into reusable resources, it is possible to mitigate its environmental impact and contribute to energy savings (Muhwezi et al., 2012).

Proper management of construction waste has become a crucial aspect of urban management, with the need to investigate various approaches for effective waste collection, recycling, disposal, and the identification of optimal landfill locations. In addition to environmental benefits, these practices contribute to economic and social advantages by reducing costs associated with raw materials, landfill space, and energy consumption (de Magalhães et al., 2017).

Irregular population growth has led to the increasing development of the construction industry and the corresponding production of construction waste. Today, finding an ideal landfill that meets environmental and economic requirements is a major objective in waste management discussions. Lack of management and targeted disposal of such waste can have devastating environmental and human effects. Therefore, during the past years, various studies have been conducted to manage and locate the construction landfill sites both in and outside of the country (Derin et al., 2020).

Several studies have applied different methodologies to address construction waste disposal.

Khodaparast et al. (2018) investigated the use of the Analytical Hierarchy Process (AHP) and Geographic Information System (GIS) for siting municipal solid waste landfills in Qom city, Iran. The study aimed to determine optimal landfill locations by considering key factors such as geomorphology and socio-environmental aspects. The research involved spatial analyses to identify suitable areas, categorizing various influencing factors. Digital layers were weighted and classified according to standards and expert judgment. Multi-criteria decision-making algorithms, including AHP and weighted linear combination, were applied to the existing layers in GIS. The findings revealed that only 7% of the study area presented very good conditions for landfill siting, corroborated by field observations. The study emphasized the importance of effective landfill site management to mitigate environmental impacts.

Rahmat et al. (2017) investigated landfill site selection in Behbahan, Iran, utilizing Geographic Information System (GIS) and the Analytic Hierarchy Process (AHP). The study aimed to address the complexities of selecting suitable sites by considering multiple criteria, including distance to groundwater, surface water, sensitive ecosystems, land cover, and proximity to urban areas and roads. A hierarchical structure was established for decision-making, and individual criteria were evaluated using a rating method. The relative importance of these criteria was determined through AHP. The Simple Additive Weighting (SAW) method was then applied to assess land suitability. Results indicated that 38% of the study area was highly suitable for landfill siting, leading to the identification of five candidate sites for further field investigation.

Chabok et al. (2020) aimed to identify optimal municipal solid waste (MSW) landfill sites in Ahvaz, Iran, using a fuzzy multi-criteria decision-making approach combined with Geographic Information System (GIS). The study employed fuzzy logic to create criteria layers in GIS and applied the Analytic Hierarchy Process (AHP) to assess land suitability. Results indicated that transportation networks and proximity to residential and commercial areas were the most significant factors influencing landfill placement, with final weights of 0.163 and 0.131, respectively. The study found that areas close to transportation routes but distant from sensitive environmental zones were the most suitable for landfills. Ultimately, 11 sites meeting the defined criteria were selected for MSW landfill. This methodology offers a valuable framework for decision-makers in selecting optimal landfill locations, allowing for the incorporation of additional factors based on regional importance.

Yalcinkaya and Kirtiloglu (2021) developed a comprehensive model for identifying suitable sites for municipal solid waste incineration facilities in Izmir, integrating fuzzy analytic hierarchy process (AHP) with Geographic Information System (GIS). The study addressed the multi-criteria decision-making challenges associated with site selection, considering both environmental and economic factors. A stepwise methodology was employed, including the creation of a spatial database, exclusion analysis, and preference analysis to determine spatial membership degrees and weights for each factor, culminating in a high-resolution land suitability map. The results indicated that a facility with a capacity of 117 MWe could effectively recover energy from 5,649 tonnes of municipal solid waste per day. Four potential sites for the incineration facility were identified. This model provides a versatile framework for decision-makers in site selection for various municipal solid waste management facilities.

Aghad et al. (2024) focused on identifying optimal solid waste disposal sites in Kenitra province, northwest Morocco, by integrating fuzzy logic with the analytic hierarchy process (fuzzy-AHP) and Geographic Information System (GIS) techniques. The study addressed the pressing issue of unsuitable disposal sites, which pose significant environmental and public health risks due to rapid urbanization and population growth. Thirteen factors influencing site selection were analyzed. The findings revealed that 5% of the study area was classified as extremely suitable for waste disposal, primarily located in the central-eastern regions, while 9% was deemed almost unsuitable, concentrated in the northern and southern areas. The results were validated using the area under the curve (AUC) of the receiver operating characteristics (ROC), achieving a moderate prediction accuracy of 57.1%. This study provides valuable insights for authorities and stakeholders in establishing new solid waste disposal sites in Kenitra province.

Locating appropriate disposal sites for construction waste is a multifaceted challenge. Multiple factors such as environmental, economic, and social criteria influence the decision-making process. Furthermore, local characteristics and specific geographic conditions must be carefully considered when selecting optimal sites. Improper site selection can lead to negative environmental and socio-economic consequences, including water and soil contamination, habitat destruction, and public health issues (Feng et al., 2022).

Geographic Information System (GIS) is a powerful tool that has proven to be highly effective in the analysis of spatial data for the purpose of decision-making (Thill , 2019). GIS enables the integration and analysis of a wide range of information, facilitating the identification of suitable landfill sites by incorporating various decision-making criteria. Its ability to process and manage large datasets makes it indispensable for urban planners and environmental scientists (Ali et al., 2024). In the context of construction waste management, GIS can be used to evaluate multiple factors such as proximity to urban centers, land use, soil type, and environmental sensitivity, among others.

This study is guided by the following hypotheses:

1). The application of multi-criteria decision-making (MCDM) models and GIS analyses will lead to the identification of optimal construction waste disposal sites in Yazd city.

2). Environmental factors such as distance from residential areas, soil type, and environmental sensitivity have a direct and significant impact on the selection of suitable sites for construction waste disposal.

The primary objective of this study is to identify suitable locations for the disposal of construction waste in Yazd city, using a combination of multi-criteria decision-making (MCDM) models and GIS technologies. This research seeks to:

1). Identify key criteria and factors influencing the selection of construction waste disposal sites.

2). Integrate these criteria into a decision-making framework using GIS and MCDM.

3). Propose optimal landfill locations that minimize environmental impact while considering economic and social factors.

The findings of this research will contribute to the sustainable development of urban areas by providing a systematic approach for the management of construction waste. Properly locating waste disposal sites is essential to mitigate the negative environmental impacts of construction activities, preserve natural resources, and promote efficient land use. The methodology developed in this study can also be adapted and applied to other cities facing similar challenges in construction waste management.

2. Materials and Methods

2.1. Study Area

Yazd city is situated in the central part of Yazd province, comprising five districts, including a historically significant district. Geographically, the city lies between the longitudes 54° 16' 43" to 54° 25' 00" east and the latitudes 31° 47' 40" to 31° 57' 08" north (Tafti et al., 2024). As a rapidly growing urban center, Yazd has been facing increasing challenges related to construction waste management due to urban expansion and population growth. The city's historical importance and unique desert landscape further complicate the management of construction and demolition waste.

For this study, the focus area was selected based on essential criteria for construction waste disposal, which included the need for sites to be located outside the densely populated urban limits but within the administrative boundaries of the city of Yazd. The study area thus encompasses both urban settlements and villages that are connected by transportation networks and regional infrastructure (Fig.1). This geographical scope allows for a comprehensive analysis of areas that may be suitable for waste disposal while avoiding direct conflict with populated areas and sensitive environmental zones.

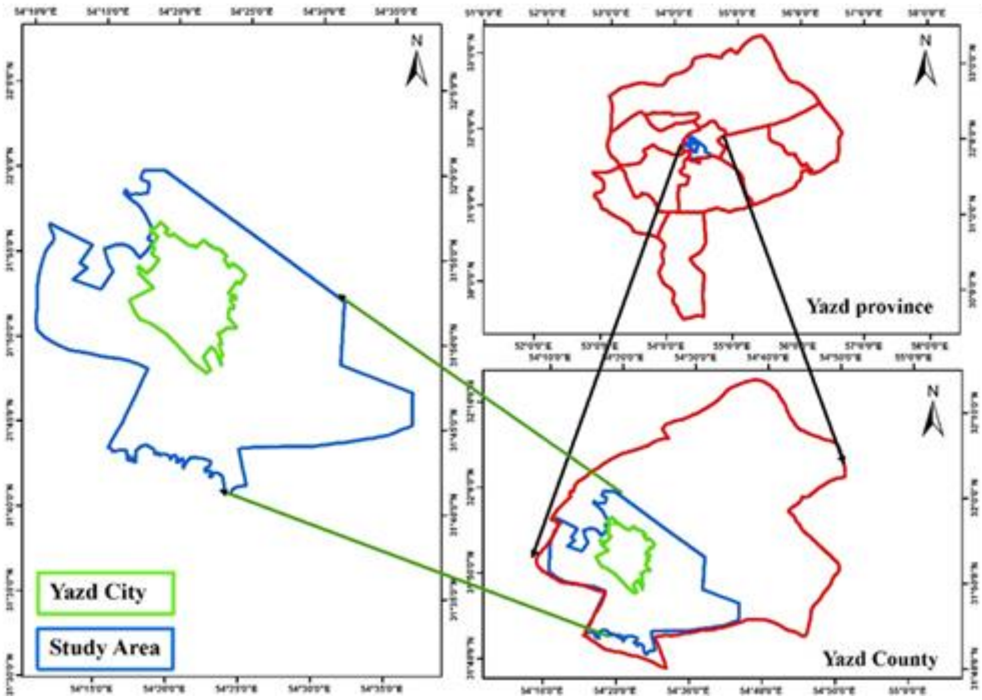


Fig. 1 – The location of the study area

According to the statistics provided by the Management, Planning, and Budget Organization of Yazd province, the population distribution of Yazd city, its neighboring cities, and surrounding villages is outlined in Table 1. This population data is crucial for understanding the potential impacts of construction waste disposal on nearby communities, particularly in terms of environmental, economic, and social considerations. The demographic data assists in evaluating proximity criteria, including how close the potential waste disposal sites are to residential areas, which is an important factor in the site selection process.

Table 1 – Population of the settlements located within the boundary of Yazd (urban and rural) in period 1986-2016

Row	Settlement Type	Name	Population in 1986	Population in 1996	Population in 2006	Population in 2011	Population in 2016
		Yazd	230,483	326,776	432,194	486,152	529,673
		Hamidia	-	13,100	27,615	37,428	51,793
1	Urban	Shahedieh	-	11115	14374	16571	18309
		Total	230483	350991	474183	540151	599775
2	Rural	-	15,276	16,070	23,556	23,540	35,652
3	-	Total Population	245,759	367,061	497,739	563,691	635,427

In this study, we aim to identify optimal sites for construction waste disposal in Yazd city through a systematic approach that incorporates various decision-making criteria. The methodology employs the Analytic Hierarchy Process (AHP) to evaluate and prioritize these criteria, ensuring a comprehensive analysis. The following workflow diagram outlines the steps taken in this research, providing readers with a clear understanding of the process before delving into the detailed findings (Fig. 2).

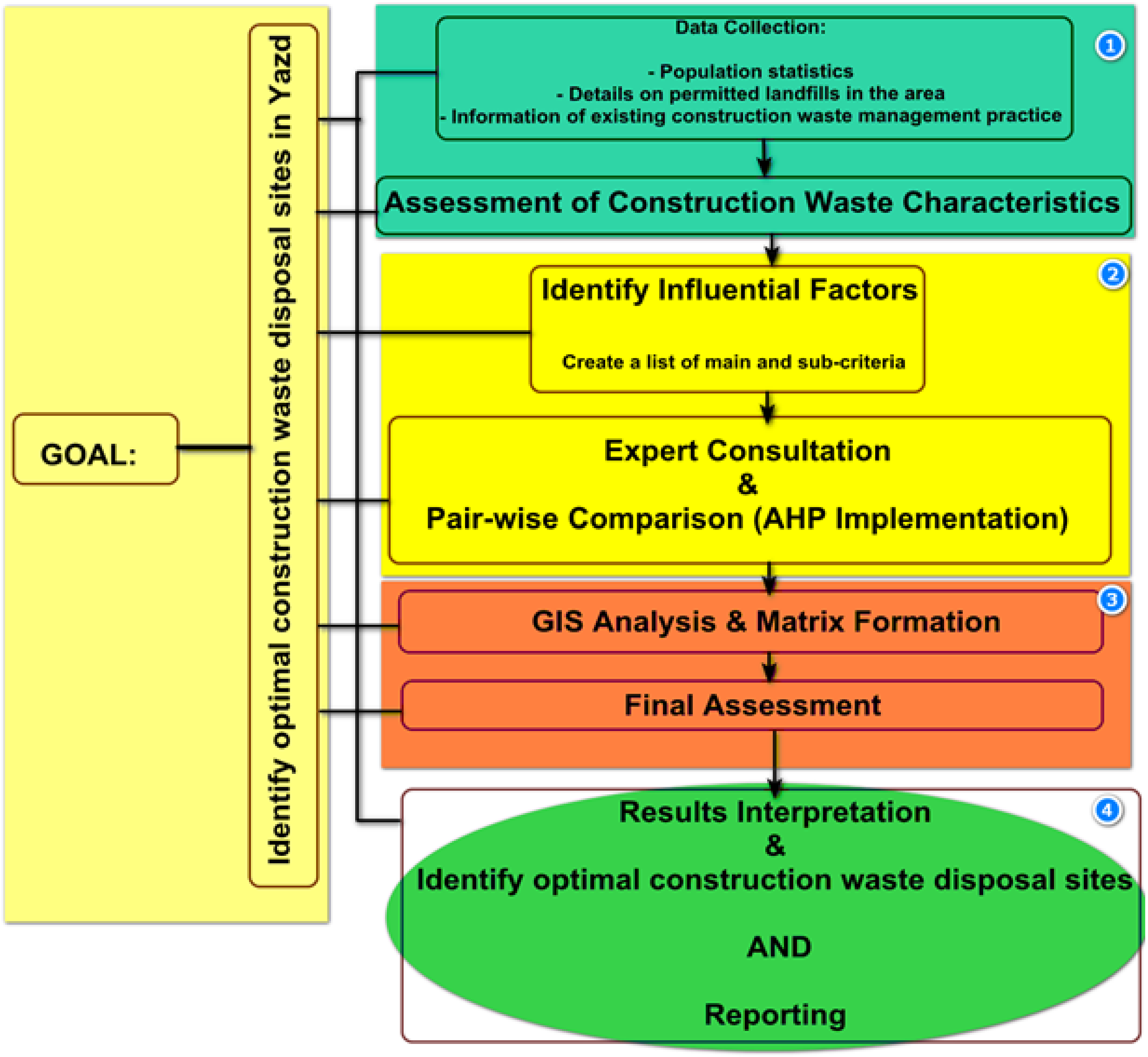


Fig. 2 – Workflow Diagram of Study

2.2. Condition of Construction Waste in Yazd

Effective management of construction waste necessitates a comprehensive understanding of its production volume, collection processes, and optimal recycling and disposal methods. In Yazd, ongoing construction and civil projects have led to a significant generation of construction waste.

According to statistics from the Yazd Municipal Waste Organization, the total production of construction waste in 2021 reached approximately 900 tons per day, marking a 200-ton increase compared to 2019. This substantial volume of construction waste poses various environmental challenges and economic burdens, as a considerable portion of municipal revenues is allocated to managing construction waste. Currently, there is no systematic separation or recycling of construction waste during disposal, although plans for such measures are under review (Morakabatchian et al., 2017). Notably, the volume of construction waste produced in Yazd is approximately 2.5 times greater than that of municipal solid waste generated daily.

Seasonal variations also influence construction waste production in Yazd, with August recording the highest volume and December the lowest. An analysis of construction permits issued from 2001 to 2010 revealed an average construction area of 19,286 square meters and an average demolition area of 1,927 square meters, indicating a 65% growth in construction activity over that decade (Morakabatchian et al., 2017). These figures are based on the study conducted in 2010, assuming no major environmental events, such as floods or earthquakes, which could further inflate current production rates.

The classification of construction waste in Yazd identifies eight distinct categories, referred to as a complete category. Results from studies indicate that cement and concrete waste constitute 38% of the total construction waste, while plastic and wooden waste each account for only 3%, representing the highest and lowest proportions of construction waste, respectively (Ansari & Ehrampoush, 2018).

Monthly analysis of construction waste production during this period indicated that November 2017 saw the lowest amount of construction waste, whereas July 2018 experienced the highest volume (Ansari & Ehrampoush, 2018).

The comprehensive waste plan for Yazd projects an annual increase in construction waste of approximately 11% every five years. Based on the 2021 statistic of 900 tons per day (equating to 328,500 tons annually), and considering the growth rate specified in the comprehensive waste plan, the estimated construction waste production for 2031 is projected to reach 405,555 tons. This indicates that the total construction waste over the ten-year period will amount to 770,555 tons. Given that experts from the Waste Management Organization estimate a requirement of 0.6 cubic meters of space for each ton of construction waste, an estimated 462,333 cubic meters of space will be necessary to manage the construction waste generated over this decade.

2.3. Currently Permitted Landfills for Construction Waste in Yazd

According to the Municipal Waste Management Organization of Yazd, as of 2021, there are three designated landfills for construction waste in the city (Fig.3):

Landfill No. 1: Located in the waste pit on Azadegan Road, past the cemetery. This site spans an area of 40 hectares and is primarily used for the disposal of construction waste generated within the city limits.

Landfill No. 2: Situated in the Bonyad pit on Hashemi Highway, behind the Fruit and Vegetable Market. This landfill covers an area of 35 hectares and serves as another critical site for managing construction waste.

Landfill No. 3: Found on Faqih Khorasani Boulevard, towards the Yazd Wastewater Treatment Plant. This landfill is dimensionally smaller, measuring 30 meters wide, 100 meters long, and 7 meters deep, but plays a vital role in the waste management system of the city.

These landfills are crucial for addressing the challenges posed by construction waste in Yazd. However, their current usage highlights the need for better waste management practices, including separation and recycling, to mitigate environmental impacts and improve overall efficiency in construction waste disposal.

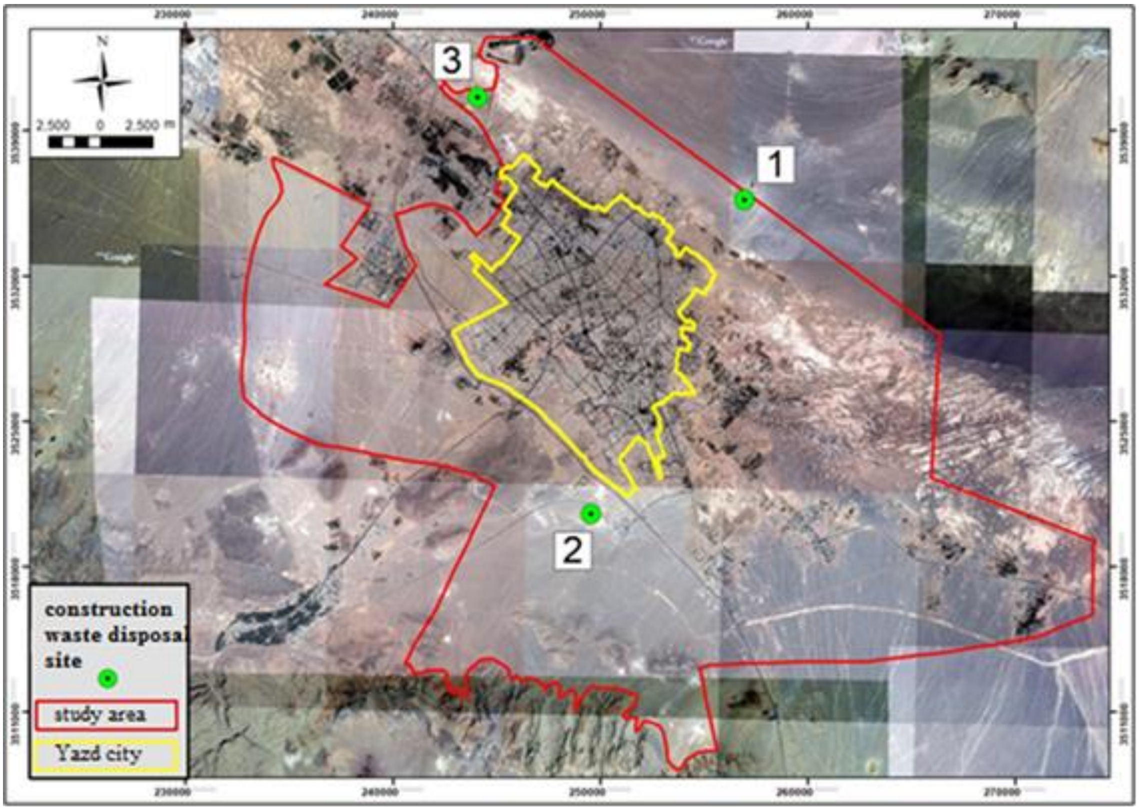


Fig. 3 - Map of the current landfills for construction waste in Yazd

2.4. Factors Influencing the Selection of Landfills for Construction Waste

The initial step in designing an effective landfill is the careful selection of an appropriate location. Several critical factors must be considered when determining the optimal site for a landfill, including:

Topography and Geology: The physical characteristics of the land, including slope, soil type, and geological stability, are essential in assessing site suitability.

Hydrology: Understanding the area's hydrology, including surface water flow and drainage patterns, is crucial to prevent contamination of local water sources.

Climatic Conditions: Local weather patterns, such as rainfall and temperature variations, can significantly affect landfill operations and waste management practices.

Required Land Area: Sufficient space must be available to accommodate projected waste volumes over the landfill's operational lifespan.

Cover Soil: The quality and availability of cover soil for daily cover and final capping must be considered to ensure proper waste management.

Groundwater Level: Proximity to groundwater can influence the risk of leachate contamination and should be monitored closely.

Land Position Relative to Urban Development: The site's location concerning existing and planned urban development is important to minimize potential conflicts with residential and commercial areas.

Waste Characteristics: Understanding the composition and properties of the waste to be disposed of helps in designing the landfill appropriately.

Adjacent Land Use: The land use surrounding the proposed landfill site can affect its acceptance by the community and regulatory bodies.

Distance from Surface Water: Maintaining an adequate distance from rivers, lakes, and other bodies of water is vital to safeguard against potential contamination.

At this stage, the criteria and sub-criteria used in locating landfills were selected based on information gathered during the survey phase, expert opinions, and relevant research from both domestic and international sources. The data required to determine the effective factors in landfill location is summarized in Table 2.

Table 2 – Main and secondary factors in locating the construction waste landfill

Row	Main factors	Secondary factors
1	Access network	-
2	Distance from population centers (urban and rural)	-
3	Distance from urban infrastructure	Airport, railway
4	Water resources	Surface water, groundwater depth, qanat, well
5	Land features	Distance from the fault, soil permeability, bedrock type, slope
6	Wind direction	
7	Distance from waste production centers	
8	Land use	Vegetation, industrial, barren, agricultural and horticultural

2.5. Hierarchical Analysis Process

The Hierarchical Analysis Process (HAP) is a structured decision-making tool used when multiple competing options and criteria must be evaluated. This method is particularly effective for situations involving both quantitative and qualitative criteria. The process begins with the construction of a hierarchical decision tree, which visually organizes the factors to be compared and the competing options under consideration. This hierarchy helps clarify the relationships among the criteria and provides a framework for analysis. Next, a series of pair-wise comparisons are conducted, where each factor is compared against others to determine their relative importance. These comparisons allow the decision-maker to assess the weight of each factor concerning the competing options being evaluated.

The final step involves synthesizing the results from the pair-wise comparison matrices. This synthesis combines the weights assigned to each factor to arrive at an optimal decision. The logic underlying the Hierarchical Analysis Process ensures that the decision reflects the relative significance of each criterion while considering the complexities of the decision context (Darko et al., 2019).

2.6. Pair-wise Comparison of Main and Sub-criteria

In this study, the effective factors for locating landfills were systematically classified into main and sub-criteria. To assess the relative importance of each criterion, questionnaires were distributed to relevant experts and specialists in the field. The responses were used to construct a binary comparison matrix for both the main and sub-criteria. The analysis revealed that factors such as the access network and proximity to population centers were identified as the most influential determinants in landfill site selection. These criteria hold significant weight in the decision-making process, reflecting their critical role in ensuring the accessibility and acceptability of the landfill sites.

To validate the accuracy of the pair-wise comparisons, an inconsistency ratio was calculated, resulting in a value of less than 0.01. This low inconsistency rate indicates a high level of agreement among the experts and confirms the reliability of the comparison process. This structured approach to pair-wise comparison not only enhances the robustness of the decision-making framework but also ensures that the selected criteria are aligned with the practical considerations of landfill site selection. This method provides a transparent and systematic approach to decision-making, enabling stakeholders to make informed choices based on a comprehensive assessment of all relevant factors.

2.7. Preparation of Distance Classification Map of Main and Sub-criteria

In this phase of the study, we focused on assessing the appropriateness of the main and sub-criteria for landfill sites designated for construction waste, particularly concerning their distance from these criteria. Utilizing expert opinions, relevant research, and Geographic Information System (GIS) analytical functions, we developed a distance classification map for both the main and sub-criteria.

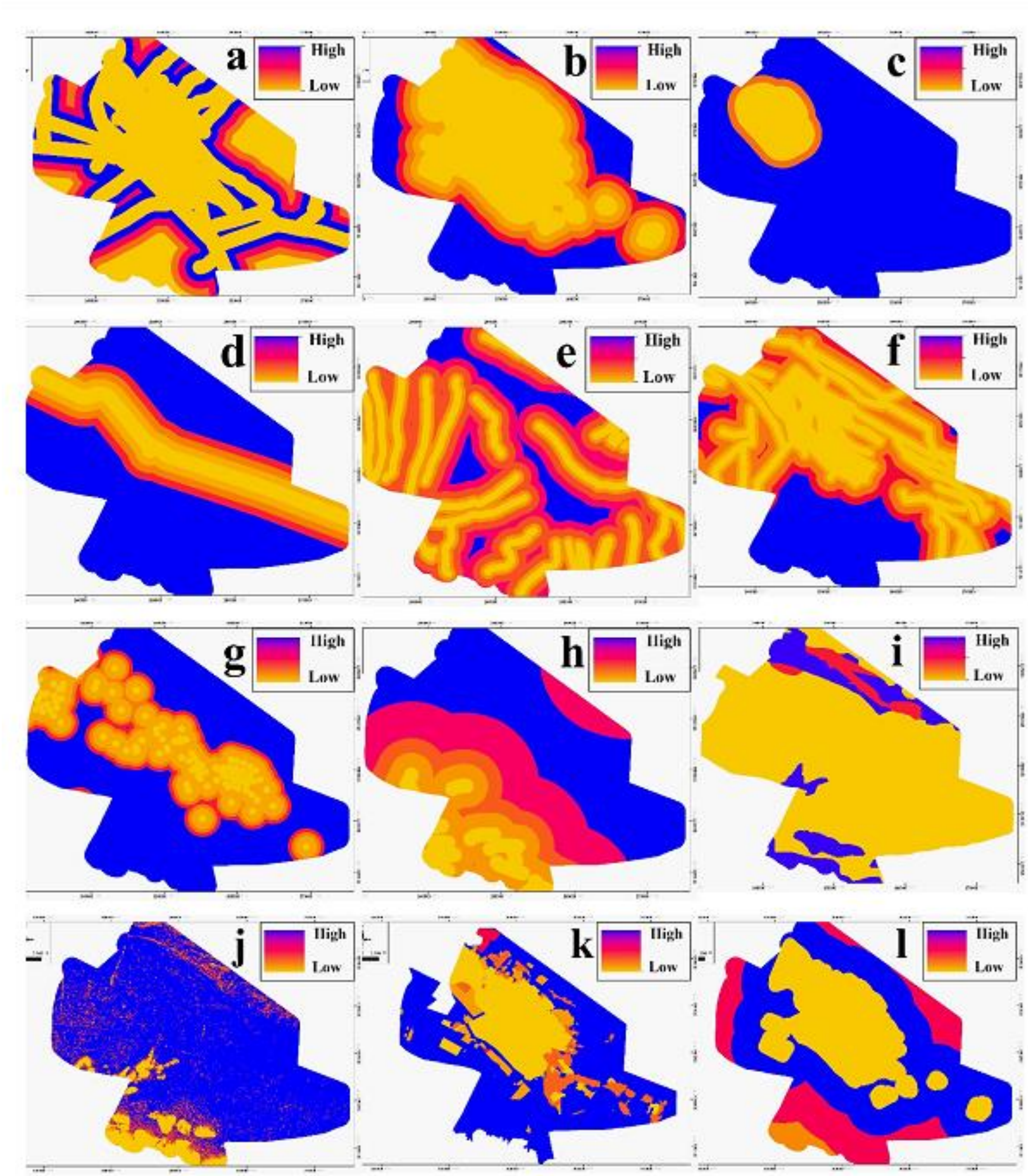
The process began by categorizing the criteria as either compatible or incompatible with landfill sites. For compatible criteria—such as the access network—the importance of proximity increased as the distance to the criterion decreased. This relationship is reflected in the relative importance values, which range from zero to one. A value approaching one indicates that the landfill site is very appropriate due to its closeness to the criterion, while a value approaching zero indicates relative inappropriateness.

Conversely, for incompatible criteria—such as residential centers—the relative importance decreases as the landfill site moves closer to these areas. In this case, the value assigned to proximity is inversely related to the appropriateness of the site. Furthermore, areas where construction waste disposal is prohibited due to restrictions (e.g., residential zones) were marked as limiting factors, assigned a relative importance value of zero. This comprehensive approach allowed us to create a detailed distance classification map that aids in the effective decision-making process for landfill site selection.

3. Results

3.1. Distance Analysis and Interpretation of the Land Suitability Map for a New Waste Disposal Site Based on Main and Secondary Criteria:

The provided image shows land suitability maps for selecting a new waste disposal site in Yazd, based on both primary and secondary criteria. Each map evaluates a specific criterion and illustrates varying degrees of land suitability using a color gradient (Fig. 4).



4 - Land suitability map for selecting a new waste disposal site based on various main and secondary criteria, including a) access network, b) population centers, c) airport, d) railway, e) surface water, f) qanat, g) water well, h) fault, i) bedrock, j) slope, k) land use, and l) waste production centers.

Below is a detailed analysis and interpretation of each map and its corresponding criteria:

Access Network (Map a):

This map considers the access network (major roads and pathways). Areas near important road networks have a higher suitability for waste disposal (red and yellow colors). The proximity to transport routes is crucial for ease of waste transport. Areas far from major roads have lower suitability (blue colors).

Population Centers (Map b):

This map highlights the proximity to population centers. Areas near human settlements are deemed less suitable for waste disposal (blue colors) due to potential environmental and health risks. More distant areas, posing fewer health hazards, are more suitable (red and yellow colors).

Airport (Map c):

The proximity to the airport is an incompatible factor, as shown in this map. Areas near airports are unsuitable for waste disposal (blue colors) due to safety and environmental concerns, such as bird strikes and odor issues. Distant areas from airports are more suitable (red and yellow colors).

Railway (Map d):

This map indicates the influence of railways on landfill site selection. Areas close to railways are more suitable (red and yellow colors) due to improved access and transportation efficiency. However, care must be taken to avoid affecting nearby population centers or sensitive environmental areas.

Surface Water (Map e):

The surface water map illustrates the impact of proximity to rivers and surface water sources. Areas near these water sources are unsuitable for waste disposal (blue colors) as they may lead to water contamination. Areas further from surface water are deemed more suitable (red and yellow colors).

Qanat (Map f):

Qanats, as important water resources in Yazd, must be protected. This map shows that proximity to qanats is a limiting factor (blue colors) due to the risk of contaminating these delicate water systems. Distant areas from qanats are more suitable (red colors).

Water Wells (Map g):

Similar to qanats, proximity to water wells is a critical restriction. The water wells map highlights that waste disposal near wells is inappropriate (blue colors) due to the potential for groundwater contamination. Areas further from wells have higher suitability.

Faults (Map h):

Active faults pose a significant risk for waste disposal due to the possibility of earthquakes. This map demonstrates that areas near faults are less suitable (blue colors). Areas distant from faults, where seismic risk is lower, are more suitable for landfill sites (red and yellow colors).

Bedrock (Map i):

Bedrock and subsurface geology play an important role in waste disposal. This map indicates that areas with poor or unsuitable bedrock fall into the "unsuitable" category (blue colors), while regions with more stable bedrock are deemed better for waste disposal.

Slope (Map j):

The slope map shows that areas with lower slopes are more suitable for waste disposal (red and yellow colors). Steep slopes (blue colors) are unsuitable due to erosion risks and the potential for waste runoff during rain events.

Land Use (Map k):

The current land use significantly influences landfill site selection. This map shows that industrial or barren lands are the most suitable for waste disposal (red and yellow colors), while agricultural and ecologically sensitive lands are considered unsuitable (blue colors).

Waste Production Centers (Map l):

Proximity to waste production centers is a key factor. Areas near these centers are more suitable for waste disposal (red and yellow colors) because reducing transportation distances minimizes both costs and environmental impacts.

Overall Conclusion:

By integrating the results of these maps, a comprehensive assessment of the most suitable areas for construction waste disposal in Yazd can be achieved. These analyses are based on environmental, economic, and social criteria, guiding policymakers and urban managers toward optimal site selection for waste disposal.

3.2. Analysis and Interpretation of Pair-wise Comparison Matrix of the Main Criteria and Relative Weights

The pair-wise comparison matrix in Table 3 evaluates the relative importance of the main criteria influencing the selection of a suitable location for construction waste disposal. Each criterion is compared with others, assigning a relative weight based on the Analytical Hierarchy Process (AHP). The final column indicates the computed relative importance for each criterion after applying the AHP method.

Table 3 - Pair-wise comparison matrix of the main criteria and the relative weight

Main criteria	Access network	Population centers	Water resources	Land use	Land features	Urban infra-structure	Waste production centers	Wind direction	Relative importance
Access network	1	1/3	1/2	3	1/3	2	4	3	0.1165
Population centers	3	1	3	4	2	4	6	5	0.3005
Water resources	2	1/3	1	3	1/2	2	4	3	0.1435
Land use	1/3	1/4	1/3	1	1/4	1/2	2	3	0.0621
Land features	3	1/2	2	4	1	3	5	4	0.2201
urban infrastructure	1/2	1/4	1/2	2	1/3	1	3	2	0.0802
waste production centers	1/4	1/6	1/4	1/2	1/5	1/3	1	1/2	0.0326
Wind direction	1/3	1/5	1/3	1/3	1/4	1/2	2	1	0.0446

3.3. Main Criteria and Weights Breakdown:

Population Centers (Relative Importance: 0.3005)

This criterion holds the highest weight (30.05%), signifying its critical role in the selection process. Population centers are key factors as the proximity of waste disposal sites to densely populated areas can have serious public health and environmental consequences. The higher the population density near the site, the more undesirable the location becomes due to the risk of pollution, odor, and public health concerns. Therefore, this criterion has been assigned the highest priority.

Land Features (Relative Importance: 0.2201)

The second most important criterion, land features, reflects the importance of natural geographical conditions such as topography, soil type, and geological stability. These features influence the feasibility of building and managing a landfill effectively. The weight (22.01%) suggests that areas with favorable land features (e.g., stable ground and low slope) are more suitable for waste disposal.

Water Resources (Relative Importance: 0.1435)

Water resources, with a weight of 14.35%, are the third most important factor. Proximity to surface and groundwater sources is a crucial consideration to avoid contamination of vital water supplies. Areas closer to water bodies are less suitable, as landfill leachate can infiltrate and contaminate water resources, posing significant risks to ecosystems and human populations.

Access Network (Relative Importance: 0.1165)

Access to transportation routes ranks fourth with a weight of 11.65%. Proximity to highways and roads is necessary for efficient waste transport, reducing costs and environmental impacts from vehicles. Sites near well-established access networks are preferable, as they ensure easier waste management operations.

Urban Infrastructure (Relative Importance: 0.0802)

Urban infrastructure, including airports and railways, contributes to the decision-making process but is given moderate importance (8.02%). Locations close to urban infrastructure could benefit from better connectivity, but the potential negative effects, such as noise and air pollution, decrease the priority of this criterion.

Land Use (Relative Importance: 0.0621)

Land use has a lower weight (6.21%) and pertains to the existing use of the land, such as agriculture, industry, or barren land. Barren or industrial lands are preferable for waste disposal as they are less likely to disrupt sensitive land uses such as agriculture or residential zones.

Wind Direction (Relative Importance: 0.0446)

Wind direction, with a weight of 4.46%, is another secondary but relevant factor. Choosing a location based on prevailing wind patterns helps minimize the spread of odors, dust, and other pollutants to nearby populated areas, but it is less critical compared to other factors.

Waste Production Centers (Relative Importance: 0.0326)

The proximity to waste production centers is assigned the lowest weight (3.26%). While close proximity reduces transport costs, the relative impact of this criterion is lower in comparison to environmental and public health considerations, making it less influential in the overall decision.

Based on the AHP analysis, population centers and land features are the two most significant criteria in the location selection process for construction waste disposal in this context. The proximity to population centers must be minimized to reduce health risks, while land features such as stability and slope play a crucial role in site feasibility. Water resources and access networks are also important but are secondary considerations. Factors such as urban infrastructure, land use, wind direction, and proximity to waste production centers are of lesser importance but still contribute to the overall decision-making process. This matrix-driven approach ensures a balanced evaluation of environmental, social, and logistical factors, leading to an informed and comprehensive selection of the most appropriate landfill site for construction waste.

3.4. Analysis of the Final Land Suitability Map for Construction Waste Disposal Sites in Yazd

The image depicts the final land suitability map for the construction of a waste disposal site in Yazd. The areas are color-coded based on their suitability, with pink indicating unsuitable areas, yellow for low suitability, red for relatively suitable, green for suitable, and blue for very suitable (Fig. 5).

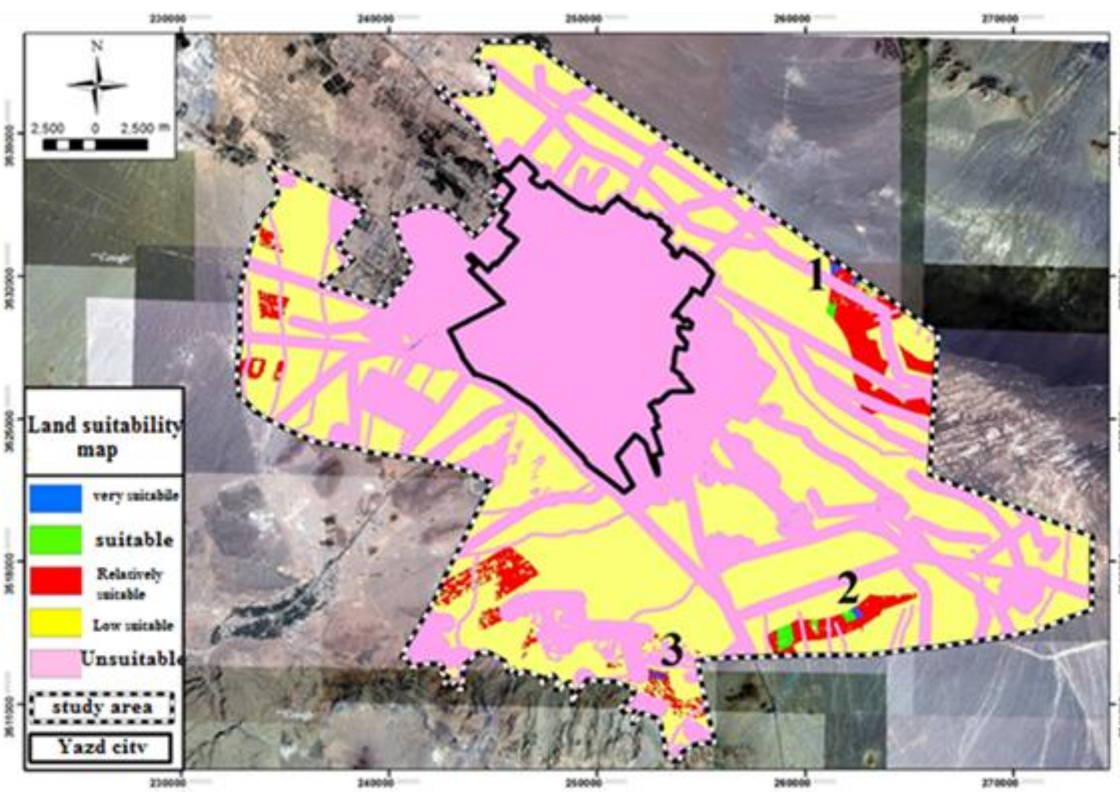


Fig. 5 - Identification of the best areas suitable for building the construction waste disposal site

3.4.1. Site 1 (Northeast of the City)

Area: 44.39 hectares

Suitability: This site has the highest weight and relative value among the identified locations, making it the best candidate for the construction waste disposal site.

Reasoning: The location is in the northeast of the city, which aligns with the dominant wind direction in Yazd. This reduces the risk of pollution and odor spreading to inhabited areas. Given its size and favorable conditions, it stands out as the most optimal choice.

3.4.2. Site 2 (Central-East)

Area: 21.17 hectares

Suitability: Ranked second in terms of priority.

Reasoning: While smaller than site 1, this location still offers substantial potential for construction waste disposal due to its suitable relative value and lower environmental risks. It is further from major population centers and falls within a less sensitive environmental zone.

3.4.3. Site 3 (South of the City)

Area: 20.6 hectares

Suitability: Although ranked third, site 3 has enough land area and relative suitability to be considered for waste disposal.

Reasoning: It is further from sensitive areas but does not benefit as much from the prevailing wind patterns, making it less suitable compared to site 1.

3.5. Comparison with Existing Waste Disposal Sites:

The map also considers the current status of construction waste disposal sites in Yazd. Three existing sites were evaluated based on similar criteria:

3.5.1 Site Near Azadegan Road (Next to Cemetery)

Status: Better suitability for construction waste disposal compared to other existing sites.

Reasoning: Despite its proximity to some sensitive areas, it is farther from population centers and has better wind direction alignment.

3.5.2. Bonyad Pit (Hashemi Rafsanjani Highway)

Status: Moderate suitability.

Reasoning: Located near industrial and military sites, it has an average ranking due to its proximity to sensitive infrastructures.

3.5.3. Site on Faqih Khorasani Boulevard (Near Wastewater Treatment Plant)

Status: Poor and unsuitable for waste disposal.

Reasoning: This site is too close to the main road network, wastewater treatment plant, and impacted by unfavorable wind direction, making it a less desirable location.

The analysis highlights Site 1 in the northeast as the most suitable area for the new construction waste disposal site in Yazd due to its size, location, and alignment with environmental criteria. Sites 2 and 3, while suitable, offer less favorable conditions. Existing landfills near Azadegan Road are also considered relatively acceptable, but other current sites lack the necessary environmental and logistical conditions for safe waste management.

This comprehensive analysis, using GIS and AHP, ensures that the decision-making process incorporates environmental, logistical, and public health considerations to select the optimal landfill site.

4. Discussion

This study utilized a multi-criteria decision-making approach, integrating Geographical Information Systems (GIS) and the Analytical Hierarchy Process (AHP), to identify and evaluate suitable locations for construction waste disposal in Yazd. The results presented here reflect a comprehensive analysis of various environmental, social, and logistical factors, ensuring that optimal locations for waste disposal are selected based on established criteria.

The land suitability map generated from this research indicated three primary locations for potential construction waste disposal sites in Yazd. These locations were assessed based on a variety of criteria, including proximity to population centers, access to transportation networks, water resources, land use, and environmental features such as slope and bedrock stability. The multi-criteria approach not only provided a ranking of these locations but also allowed for a holistic assessment of potential risks and benefits associated with each site.

Among the criteria, the proximity to population centers was found to be the most important factor (relative importance of 30.05%). This result aligns with previous studies, such as those by Ghazifard et al. (2016) and Gilvari et al. (2019), which emphasized that waste disposal sites located near densely populated areas can lead to serious public health concerns, including air and water pollution, odors, and increased risk of diseases. Therefore, minimizing proximity to these areas is a fundamental consideration in the waste management process.

The second most influential criterion was land features (22.01%), including slope and soil stability. This is consistent with findings from Kang et al. (2024), who highlighted the importance of topographical and geological stability in landfill site selection, particularly in arid regions like Yazd where soil erosion and surface runoff can significantly impact the long-term sustainability of waste disposal sites. Our analysis confirms that areas with low slopes and stable bedrock are preferred for construction waste disposal, as they minimize the risks of waste leakage and environmental contamination.

Interestingly, while water resources ranked third in importance (14.35%), it remains a critical factor in regions like Yazd, where water scarcity is a major concern. Prior studies by Mallick (2021) have demonstrated the severe consequences of groundwater contamination near landfill sites in arid environments. Our study also reinforces these concerns, showing that sites close to qanats and water wells are highly unsuitable due to the potential for leachate infiltration into water sources.

The importance of access networks (11.65%) in our findings echoes the work of Stemn and Kumi-Boateng (2019), who showed that efficient transportation routes are vital for the economic viability and operational success of waste disposal facilities. Proximity to highways and main roads reduces transportation costs and minimizes the environmental impact of waste transport. However, this criterion, while significant, is still secondary to the environmental and public health factors that are more directly linked to the safety and sustainability of landfill sites.

In terms of methodology, our study shares commonalities with similar GIS-based waste disposal site selection studies in Iran and other regions. For example, Elkhrachy (2023) also used AHP to assess landfill locations in semi-arid environments, highlighting the critical role of local environmental factors such as slope, soil composition, and water resources. However, our study offers a more detailed analysis by incorporating additional layers, such as wind direction and urban infrastructure, which are often neglected in comparable research.

Moreover, when comparing our findings to global studies, such as Feng (2022) in China, we find that the weight assigned to population centers is consistently high across different geographical contexts. The focus on minimizing public exposure to waste-related hazards is a universal concern, although the relative importance of other factors, such as urban infrastructure and transportation, varies depending on the local context.

The results of this study have practical implications for urban planners and policymakers in Yazd. Site 1, located in the northeast of the city, emerged as the most suitable location for a construction waste disposal site, covering an area of 44.39 hectares. Its distance from population centers, alignment with prevailing wind directions, and favorable land features make it an optimal choice for future waste management efforts. This site not only minimizes environmental risks but also takes into account logistical considerations such as access to main roads.

Site 2, although smaller in size (21.17 hectares), also presents a viable option, particularly due to its lower environmental risks and relative distance from sensitive areas. However, Site 3 (20.6 hectares) is less favorable due to its suboptimal location relative to wind patterns and proximity to key transportation routes, which could lead to potential public exposure to pollutants.

In terms of existing waste disposal sites, the site near Azadegan Road was found to be relatively suitable for continued use, as it benefits from favorable environmental conditions. However, other existing sites, such as those near Hashemi Rafsanjani Highway and Faqih Khorasani Boulevard, were deemed less suitable due to their proximity to industrial zones, wastewater treatment plants, and main road networks, which increase the risk of pollution and public health hazards.

While this study provides a robust framework for waste disposal site selection, several limitations should be acknowledged. First, the static nature of GIS data means that the dynamic changes in urban expansion, population growth, and industrial development may affect the suitability of the identified sites over time. Future research should incorporate temporal analysis to assess how these factors evolve. Additionally, the potential impacts of climate change, particularly in arid regions like Yazd, should be considered in future site selection models.

Finally, while the AHP method used here provides a systematic approach for weighting criteria, other multi-criteria decision-making techniques such as fuzzy logic or TOPSIS could be employed in future studies to assess the robustness of the results.

In conclusion, this study successfully applied GIS and AHP methodologies to identify the most suitable sites for construction waste disposal in Yazd. The results indicate that Site 1 in the northeast is the most optimal location based on environmental, logistical, and social criteria. The findings contribute to the broader literature on waste management in arid regions and offer practical guidance for policymakers. However, continuous monitoring and future research are necessary to ensure the long-term sustainability of these sites, particularly in the face of urbanization and environmental change.

5. Conclusion

This study aimed to identify the most suitable locations for construction waste disposal in Yazd, using a combination of Geographical Information Systems (GIS) and the Analytical Hierarchy Process (AHP). By incorporating a comprehensive set of criteria—including environmental, social, and logistical factors—this study provided an objective framework for landfill site selection that can inform future urban planning and environmental management strategies.

Population centers and land features emerged as the two most critical factors in selecting suitable waste disposal sites. Proximity to densely populated areas poses significant public health risks, while stable land features, such as low slope and solid bedrock, enhance the long-term safety and feasibility of waste disposal operations.

Water resources, particularly the proximity to qanats and water wells, were found to be crucial limiting factors. Protecting Yazd’s fragile water systems from potential contamination is vital, particularly in an arid region where water scarcity is a constant concern.

Access to transportation networks was shown to have a significant impact on the operational efficiency of waste disposal sites. Sites near major roads and highways offer logistical advantages, reducing transportation costs and minimizing environmental impacts from waste transport.

The final land suitability map identified three potential sites, with Site 1 (Northeast of the City) standing out as the most suitable location due to its distance from population centers, alignment with wind direction, and favorable topographical features. Site 2 (Central-East) and Site 3 (South of the City) were also identified as viable alternatives, albeit with slightly lower suitability scores.

Among the existing waste disposal sites in Yazd, the site near Azadegan Road was found to be relatively acceptable, whereas the Bonyad Pit and the Faqih Khorasani Boulevard site were deemed unsuitable due to their proximity to sensitive infrastructures and poor environmental conditions.

Based on the findings, several recommendations can be made for policymakers, urban planners, and environmental agencies involved in waste management:

Prioritize Site 1 for Future Waste Disposal Projects: Site 1 in the northeast should be prioritized for the development of a new construction waste disposal facility. Its distance from residential areas and alignment with wind direction make it the safest and most sustainable option.

Close and Rehabilitate Unsuitable Existing Sites: The existing sites near Faqih Khorasani Boulevard and Bonyad Pit should be considered for closure or repurposing, as they pose significant environmental and public health risks. A well-structured rehabilitation plan should be implemented to mitigate any long-term damage to the surrounding environment.

Monitor and Protect Water Resources: Given the importance of water resources in Yazd, waste disposal sites should be rigorously monitored to prevent groundwater contamination. Special attention should be given to qanats and water wells, ensuring that buffer zones are strictly maintained.

Implement Long-term Monitoring and Maintenance Plans: To ensure the sustainability of the selected sites, continuous monitoring should be implemented, particularly in areas prone to environmental changes. This should include regular checks for groundwater contamination, soil stability, and landfill gas emissions.

Engage Stakeholders in Decision-Making: Involving local communities and key stakeholders in the decision-making process can enhance public trust and ensure that environmental and public health concerns are adequately addressed. Community engagement should be a core part of future waste disposal projects.

Explore Alternative Waste Management Strategies: While landfilling remains a necessary solution for construction waste, the local government should also explore alternative waste management strategies, such as recycling and material recovery facilities (MRFs), to reduce the overall volume of waste being disposed of in landfills.

Incorporate Climate Change Projections in Future Planning: Given the region’s vulnerability to climate change, particularly increased temperatures and reduced rainfall, future waste management strategies should consider the potential impacts of climate change on site suitability, groundwater levels, and infrastructure resilience.

In conclusion, this study provides a valuable framework for the sustainable management of construction waste in Yazd. By integrating GIS and AHP methodologies, decision-makers are equipped with a data-driven approach to ensure that future waste disposal facilities are both environmentally safe and operationally efficient. The implementation of the recommendations outlined here will contribute to a cleaner, healthier, and more sustainable urban environment for Yazd, ensuring that waste management practices align with the city's long-term growth and environmental goals.

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References

Aghad, M., Manaouch, M., Sadiki, M., Pham, Q. B., & Al Karkouri, J. (2024). Integrating fuzzy-AHP and GIS for solid waste disposal site selection in Kenitra province, NW Morocco. *Environmental Monitoring and Assessment*, *196*(6), 537. https://doi.org/10.1007/s10661-024-12711-1

Ali, A., Hadeed, M. Z., Safavi, S., & Ahmad, M. (2024). Leveraging GIS for Environmental Planning and Management. In *Global Challenges for the Environment and Climate Change* (pp. 308-331). IGI Global. 10.4018/979-8-3693-2845-3.ch016

Ansari, M., & Ehrampoush, M. H. (2018). Quantitative and qualitative analysis of construction and demolition waste in Yazd city, Iran. *Data in brief*, *21*, 2622-2626. https://doi.org/10.1016/j.dib.2018.10.141

Chabok, M., Asakereh, A., Bahrami, H., & Jaafarzadeh, N. O. (2020). Selection of MSW landfill site by fuzzy-AHP approach combined with GIS: Case study in Ahvaz, Iran. *Environmental Monitoring and Assessment*, *192*, 1-15. https://doi.org/10.1007/s10661-020-08395-y

Darko, A., Chan, A. P. C., Ameyaw, E. E., Owusu, E. K., Pärn, E., & Edwards, D. J. (2019). Review of application of analytic hierarchy process (AHP) in construction. International journal of construction management, 19(5), 436-452.

Derin, P., Yeşilnacar, M. İ., & Çullu, M. A. (2020). A study on evaluation of site selection in sanitary landfill with regard to urban growth. *Environmental Research and Technology*, *4*(2), 117-125. https://doi.org/10.35208/ert.841200

de Magalhães, R. F., Danilevicz, Â. D. M. F., & Saurin, T. A. (2017). Reducing construction waste: A study of urban infrastructure projects. *Waste management*, *67*, 265-277. https://doi.org/10.1016/j.wasman.2017.05.025

Elkhrachy, I., Alhamami, A., & Alyami, S. H. (2023). Landfill Site Selection Using Multi-Criteria Decision Analysis, Remote Sensing Data, and Geographic Information System Tools in Najran City, Saudi Arabia. *Remote Sensing*, *15*(15), 3754. https://doi.org/10.3390/rs15153754

Feng, J. (2022). An integrated multi-criteria decision-making method for hazardous waste disposal site selection. *Environment, Development and Sustainability*, *24*(6), 8039-8070. https://doi.org/10.1007/s10668-021-01772-8

Ghazifard, A., Nikoobakht, S., & Azarafza, M. (2016). Municipal waste landfill site selection based on environmental, geological and geotechnical multi-criteria: A case Study. *Iranian Journal of Environmental Technology*, *2*(1), 49-67. https://doi.org/10.22108/ijet.2018.107396.1003

Gilvari, S., Mazloumi Bajestani, A., Kashfi, S. A., & Sarsangi Aliabad, A. (2019). The Need for Environmental Assessment and Field Surveys in Landfill Location Studies (Case Study: Yazd City). Journal of Radar and Optical Remote Sensing and GIS, 2(3.4), 34-48.

Mallick, J. (2021). Municipal solid waste landfill site selection based on fuzzy-AHP and geoinformation techniques in Asir Region Saudi Arabia. *Sustainability*, *13*(3), 1538. https://doi.org/10.3390/su13031538

Morakabatchian, M., Almodaressi, S. A., Barzegar, M. R., & Mokhtari, M. (2017). Optimization of Waste Collection System Using Underground Containers with Source Separation Plan (Case Study: District 3 of Yazd Municipality, Iran). *Journal of Environmental Health and Sustainable Development*, *2*(4), 422-431.

Muhwezi, L., Kiberu, F., Kyakula, M., & Batambuze, A. O. (2012). An assessment of the impact of construction activities on the environment in Uganda: A case study of Iganga municipality. *Journal of construction Engineering and Project Management*, *2*(4), 20-24. https://doi.org/10.6106/JCEPM.2012.2.4.020

Kang, Y. O., Yabar, H., Mizunoya, T., & Higano, Y. (2024). Optimal landfill site selection using arcgis multi-criteria decision-making (mcdm) and analytic hierarchy process (ahp) for kinshasa city. *Environmental Challenges*, *14,* 100826. https://doi.org/10.1016/j.envc.2023.100826

Khodaparast, M., Rajabi, A. M., & Edalat, A. (2018). Municipal solid waste landfill siting by using GIS and analytical hierarchy process (AHP): a case study in Qom city, Iran. *Environmental earth sciences*, *77,* 1-12. https://doi.org/10.1007/s12665-017-7215-3

Rahmat, Z. G., Niri, M. V., Alavi, N., Goudarzi, G., Babaei, A. A., Baboli, Z., & Hosseinzadeh, M. (2017). Landfill site selection using GIS and AHP: a case study: Behbahan, Iran. *KSCE Journal of Civil Engineering*, *21*, 111-118. https://doi.org/10.1007/s12205-016-0296-9

Sharma, N., Kalbar, P. P., & Salman, M. (2022). Global review of circular economy and life cycle thinking in building Demolition Waste Management: A way ahead for India. *Building and Environment*, *222,* 109413. https://doi.org/10.1016/j.buildenv.2022.109413

Stemn, E., & Kumi-Boateng, B. (2019). Hazardous waste landfill site selection in Western Ghana: An integration of multi-criteria decision analysis and geographic information system. *Waste Management & Research*, *37*(7), 723-736. https://doi.org/10.1177/0734242X19854530

Tafti, M. D., Monavari, S. M., Dehabadi, A. M., & Karbassi, A. (2024). Location of a municipal solid waste landfill using COCOSO, MAIRCA, MARCOS, and geographic information system (case study: Yazd). https://doi.org/10.21203/rs.3.rs-3899390/v1

Thill, J. C. (Ed.). (2019). *Spatial multicriteria decision making and analysis: a geographic information sciences approach*. Routledge.

Ugwuanyi, R., & Isife, T. (2012). Urbanization and solid waste management challenges in Nigeria. *Technoscience Review*, *3*(1/2), 13-26.

Yalcinkaya, S., & Kirtiloglu, O. S. (2021). Application of a geographic information system-based fuzzy analytic hierarchy process model to locate potential municipal solid waste incineration plant sites: A case study of Izmir Metropolitan Municipality. *Waste Management & Research*, *39*(1), 174-184. https://doi.org/10.1177/0734242X20939636