

Landfill Site Selection using GIS: Geological and Geoenvironmental Criteria for Feyzabad, Iran

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Abstract: Effective landfill site selection is crucial for sustainable waste management and minimizing environmental risks. Geographic Information System (GIS)-based approaches have become essential tools in evaluating potential landfill locations by integrating geological, environmental, and geo-environmental criteria. This study focuses on the selection of an optimal landfill site for Feyzabad, Razavi Khorasan, Iran, using a GIS-based multi-criteria decision analysis (MCDA). The methodology involves identifying suitable landfill sites by considering geological, environmental and Geoenvironmental factors. Data from remote sensing, topographic maps, and field surveys were processed using GIS spatial analysis tools to generate suitability maps. Analytical Hierarchy Process (AHP) was applied to weight different factors based on their relative importance. The results highlight the most suitable landfill locations that comply with regulatory and sustainability standards while minimizing environmental hazards. The findings of this study provide a scientific and practical framework for policymakers and urban planners to make informed decisions regarding waste disposal infrastructure. The GIS-based methodology ensures a systematic and objective selection process, reducing potential socio-environmental conflicts. Future research should consider additional socio-economic factors and climate change projections to further refine landfill site selection strategies.

Keywords: Landfill site selection, GIS, Geological criteria, Environmental impact, Geoenvironmental analysis.

I. INTRODUCTION

Waste management is a systematic approach to handling, processing, and disposing of waste materials in an environmentally responsible manner. It includes various strategies such as waste reduction, recycling, composting, energy recovery, and landfilling (Nanda & Berruti, 2021). Effective waste management is essential for minimizing environmental pollution, conserving natural resources, and protecting public

health (Warith, 2003). As urbanization and industrialization increase, the volume of waste generated continues to rise, making sustainable waste management a global challenge (Laner et al., 2012). Governments and municipalities implement policies and technologies to ensure efficient waste collection, segregation, treatment, and disposal while promoting circular economy principles to reduce waste generation (Kamaruddin et al., 2017).

Despite advancements in waste treatment technologies, landfills remain an integral component of waste management systems (Komilis et al., 1999). They serve as the final disposal sites for non-recyclable and non-compostable waste, providing a controlled environment to prevent pollution (Sumathi et al., 2008). Modern engineered landfills incorporate protective measures such as liners, leachate collection systems, and methane gas recovery to minimize environmental impact (Davoli et al., 2010). Figure 1 provides a topical modern landfill site. While landfills are necessary for managing residual waste, their sustainability depends on proper site selection, design, and management (Klein et al., 2001). Integrating landfills with waste reduction, recycling, and energy recovery initiatives helps reduce landfill dependency and promotes a more sustainable waste management approach (Andriani & Atmaja, 2019).

A landfill is a designated site for the controlled disposal of solid waste, designed to minimize environmental and public health risks (Vaverková, 2019). Landfills serve as the final destination for non-recyclable and non-compostable waste, playing a crucial role in waste management systems worldwide (Nanda & Berruti, 2021). Modern landfills are engineered to reduce contamination of soil, water, and air through protective measures such as liners, leachate collection systems, and gas recovery mechanisms (Klein et al., 2001). Despite advancements in waste processing technologies, landfilling remains an essential method for managing municipal, industrial, and hazardous waste (Warith, 2003; Azarafza et al., 2015). The site selection for landfills is a critical process that directly affects environmental sustainability, public health, and economic efficiency (Donevska et al., 2021).

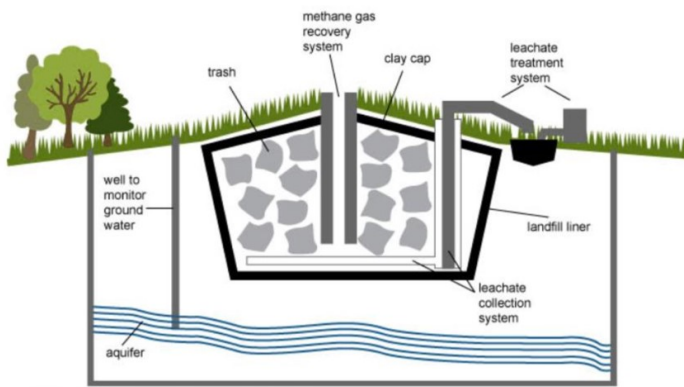


Fig. 1 A common arrangement of a modern landfill (Perenich et al., 2021)

Poorly chosen landfill locations can result in groundwater contamination, air pollution, and land degradation, leading to severe ecological and health hazards (Şener et al., 2006). On the other hand, well-planned landfill sites can significantly mitigate these risks while ensuring efficient waste disposal and resource recovery (Wang et al., 2018). Thus, landfill site selection must be conducted using a scientific and systematic approach that incorporates multiple environmental, geological, socio-economic, and regulatory criteria (Ghazifard et al., 2016). The necessity for landfill site selection arises from the increasing volume of solid waste generated due to urbanization, population growth, and industrial expansion (Eskandari et al., 2015). Many cities struggle with waste disposal challenges, leading to the illegal dumping of waste and environmental pollution (Donevska et al., 2021). Selecting a landfill site based on scientific criteria helps to optimize waste management systems and ensures compliance with environmental regulations. It also enhances long-term sustainability by reducing the negative impacts associated with improper waste disposal (Rahmat et al., 2017).

A well-located landfill minimizes environmental risks by preventing the contamination of groundwater and surface water sources (Akbari et al., 2008). This is particularly important in regions with high water table levels or in proximity to ecologically sensitive areas. Advanced landfill designs, combined with proper site selection, can effectively manage leachate and reduce the risk of water pollution (Kareem et al., 2021). Furthermore, selecting a site away from residential areas helps mitigate health risks associated with odor, air pollution, and disease vectors such as rodents and insects (Eskandari et al., 2015). From an economic perspective, landfill site selection impacts the cost of waste transportation and infrastructure development (Ghazifard et al., 2016). A site located too far from urban centers increases fuel consumption, vehicle emissions, and operational expenses (Şener et al., 2006). On the other hand, a landfill located too close to residential or commercial zones may cause social conflicts and property devaluation. A well-planned location strikes a balance between accessibility, cost-effectiveness, and environmental safety (Wang et al., 2018).

The use of Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA) has significantly improved landfill site selection processes (Ali et al., 2021). GIS enables spatial analysis of various environmental and geological parameters, helping decision-makers identify the most suitable

locations (Javaheri et al., 2007). Factors such as soil stability, land use, proximity to water bodies, and regulatory constraints can be integrated into GIS models to generate suitability maps. MCDA techniques, such as the Analytical Hierarchy Process (AHP), help prioritize different factors based on their relative importance, ensuring an objective decision-making process (Ghazifard et al., 2016).

Despite its advantages, landfill site selection faces several challenges and limitations (Donevska et al., 2021). One major limitation is land availability, particularly in densely populated urban areas where open spaces are limited. Additionally, opposition from local communities, known as the “Not in My Backyard (NIMBY)” phenomenon, often complicates site selection processes (Simsek et al., 2014). Public concerns regarding health risks, property devaluation, and environmental degradation can lead to legal disputes and delays in landfill development (Gallo, 2019). Effective public engagement and transparent decision-making are crucial to overcoming these challenges (Salleh et al., 2017). Another limitation is the long-term environmental impact of landfills (Ghazifard et al., 2016). Even with advanced containment technologies, landfills can still pose risks such as methane emissions, soil degradation, and groundwater contamination (Şener et al., 2006). Sustainable waste management strategies, including waste reduction, recycling, and composting, should be integrated with landfill planning to minimize reliance on landfills (Rahmat et al., 2017). Additionally, post-closure monitoring and rehabilitation plans should be in place to restore landfill sites once they reach capacity (Akbari et al., 2008). Selecting a landfill site is not only an environmental and economic issue but also a policy and governance challenge (Wang et al., 2018). Governments and municipalities must enforce strict regulations and conduct comprehensive environmental impact assessments (EIA) before approving landfill projects (Javaheri et al., 2007). The best international practices, such as those outlined by the US Environmental Protection Agency (USEPA), should be considered to ensure sustainable landfill management (Ghazifard et al., 2016). Interdisciplinary collaboration among geologists, environmental scientists, urban planners, and policymakers is essential for effective landfill site selection (Yal & Akgün, 2013).

The design and siting of landfills must comply with strict environmental and engineering standards to ensure safe and sustainable waste disposal (Eskandari et al., 2015). Several international organizations, such as the USEPA, the European Union Landfill Directive (1999/31/EC), and the World Health Organization (WHO), provide comprehensive guidelines for landfill development (Wang et al., 2018). These standards aim to protect groundwater and surface water, minimize air pollution, reduce greenhouse gas emissions, and ensure public safety (Mat et al., 2017). Proper landfill siting and design help mitigate environmental risks and enhance the long-term sustainability of waste management systems (Abujayyab et al., 2016). One of the key siting criteria outlined by the EPA’s Resource Conservation and Recovery Act (RCRA) is the selection of locations that minimize groundwater contamination risks (Grasso, 2017). The standards require landfills to be placed in areas with low permeability soils, such as clay, to prevent leachate infiltration into groundwater (Butt et al., 2008). Additionally, landfills must

be located at least 200m away from water bodies to reduce contamination risks (Wang et al., 2018). The EU Landfill Directive also mandates that landfill sites undergo thorough hydrogeological assessments before approval to ensure groundwater protection (Vasiljević et al., 2012). Another critical factor in landfill siting is proximity to human settlements. According to the USEPA Subtitle D Regulations, municipal solid waste landfills must be located at a sufficient distance from residential areas to minimize health hazards, odor nuisance, and air pollution (Wang et al., 2018). The WHO Guidelines for Community Health suggest that landfills should be at least 500 meters away from residential zones to reduce exposure to harmful gases and disease vectors (Grasso, 2017). Additionally, landfills should not be located in areas prone to natural disasters such as earthquakes, landslides, or floods, as recommended by the United Nations Environmental Programme (UNEP).

The primary objective of this study is to identify the most suitable landfill site for Feyzabad, Razavi Khorasan, Iran, using a GIS-based MCDA approach. This research aims to integrate geological, environmental, and geo-environmental factors to ensure sustainable waste disposal while minimizing ecological and public health risks. Specifically, the study seeks to (1) evaluate geological suitability by analyzing soil composition, bedrock stability, and seismic activity; (2) assess environmental parameters such as proximity to water bodies, protected areas, and land use patterns to mitigate pollution risks; (3) incorporate geo-environmental factors, including groundwater vulnerability and air quality impact, to prevent long-term environmental degradation; and (4) utilize GIS spatial analysis and the AHP to generate a landfill suitability map that aligns with regulatory and sustainability standards. The findings of this study will provide a scientific framework for policymakers and urban planners to make informed decisions regarding landfill site selection, ensuring efficient and environmentally responsible waste management in the region.

II. FEYZABAD LANDFILL

A. Study Location

Feyzabad is the capital of Mahvelat County, located in Razavi Khorasan Province, northeastern Iran. The city lies approximately 200 km southwest of Mashhad, the provincial capital, and serves as an important administrative and economic center for the region (Abadi et al., 2022). Location of the studied region has been provided in Figure 2. Feyzabad is known for its agricultural activities, particularly the cultivation of saffron and other crops, which play a vital role in the local economy. The city is also historically significant, with notable families, such as the Moeini Feyzabadi family, originating from this area (Dermani & Eskandari, 2016). The region's topography consists of a combination of plains, rolling hills, and mountainous areas, which influence infrastructure development and land use planning (Abadi et al., 2022). Given its semi-arid climate, characterized by hot summers and cold winters, water scarcity is a significant concern, making it essential to carefully assess potential landfill sites to prevent groundwater contamination (Rabiei-Dastjerdi et al., 2021). Selecting a landfill site in this region requires evaluating geological stability, soil composition, and hydrological conditions to minimize environmental risks.

From a hydrogeological perspective, Feyzabad depends on groundwater sources and seasonal rivers for drinking water, agriculture, and industrial use. The Iranian Department of Environment (DOE) mandates that landfill sites be located away from critical groundwater recharge zones to prevent contamination (Parsasadr et al., 2016). International standards, such as the USEPA regulations, also emphasize the need for buffer zones between landfills and water bodies. A thorough GIS-based hydrogeological assessment is necessary to ensure landfill site safety (Ghazifard et al., 2016). Feyzabad's land use and economic structure must be considered when determining landfill locations. The region is largely agricultural, with extensive saffron fields, orchards, and rangelands. Improper landfilling could negatively impact farming activities and soil quality. Additionally, the presence of urban settlements and protected natural areas necessitates a site selection process that avoids ecological damage and minimizes conflicts with local communities. GIS-based multi-criteria analysis will help in selecting a site that balances environmental protection, economic viability, and land use compatibility.

From a socio-economic perspective, landfill placement affects both waste management efficiency and public acceptance (Abadi et al., 2022). A landfill located too far from the city would increase transportation costs, fuel consumption, and carbon emissions, whereas one placed too close to residential zones may lead to public opposition due to concerns over odor, pollution, and health risks. Adopting a participatory approach, where stakeholders and local authorities are involved in the decision-making process, can help mitigate resistance and ensure a socially acceptable site selection. Feyzabad is situated within a geologically diverse region characterized by a combination of sedimentary, volcanic, and metamorphic rock formations. The underlying bedrock primarily consists of sedimentary deposits, including limestone, sandstone, and clay layers, which are interspersed with areas of igneous and metamorphic rocks, such as basalt and marble (Aghanabati, 2012). The region's geological history is marked by significant tectonic activity, leading to the formation of fault lines and earthquake-prone areas (Mirzabeygi et al., 2017).

Figure 3 is provided with the geological map of the studied region. The compaction and permeability of soil in the region vary, with some areas more suitable for construction and others requiring careful assessment, especially when considering the potential for waste containment in landfills. The presence of sedimentary layers in certain areas provides some natural advantages for landfill siting due to their ability to act as a barrier to leachate migration. The soil composition in Feyzabad also varies based on the region's topography. The flat plains and valley areas often have alluvial soils, which are more porous and may require additional engineering measures to prevent contamination of groundwater (Aghanabati, 2012). In contrast, the hilly and mountainous areas may have more compact clay soils, which are favorable for landfill site development due to their lower permeability and better containment characteristics. These variations in the region's geology play a significant role in the suitability of potential landfill sites.

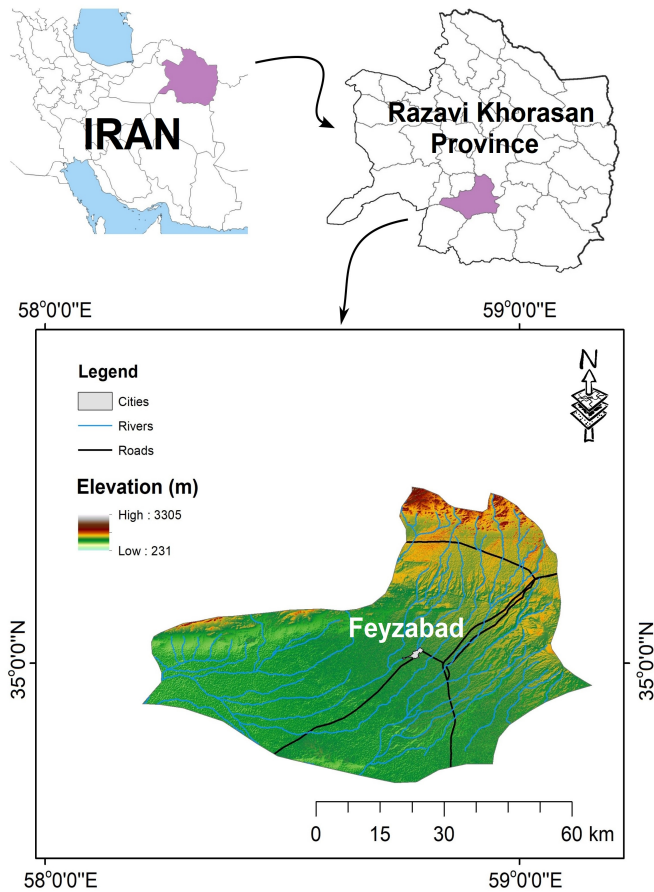


Fig. 2 Location of studied area

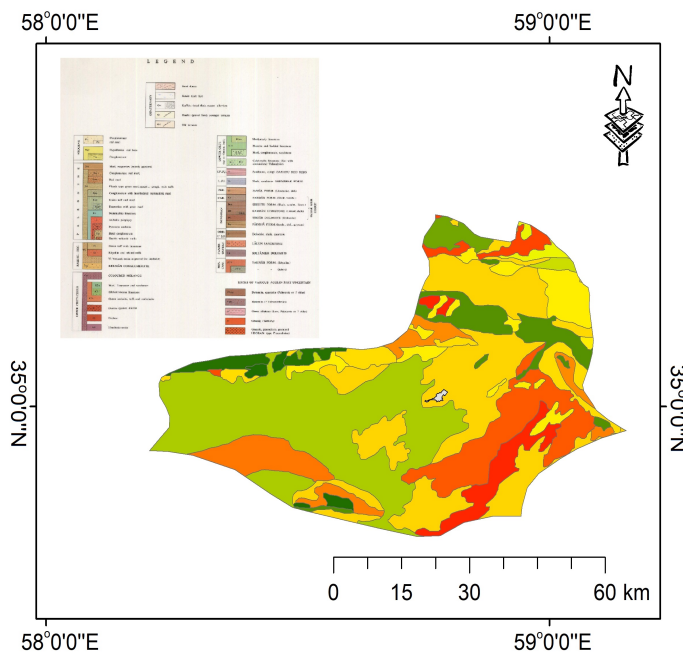


Fig. 3 Geological map of the studied area
(Geological Survey of Iran, 2009)

The drainage network in the Feyzabad region is dominated by several seasonal rivers and dry riverbeds that run through the semi-arid landscape (Parsasadr et al., 2016). The most prominent river in the area is the Jajarm River, which flows through the central part of Mahvelat County and supplies water to local agricultural and domestic needs. The region's rivers primarily rely on seasonal rainfall and snowmelt from the surrounding mountainous areas, making water availability highly variable throughout the year (Aghanabati, 2012). These seasonal rivers are critical for local irrigation, but during periods of low rainfall, their flow can significantly decrease, leading to water scarcity. The presence of these rivers, along with other smaller seasonal streams and natural drainage channels, must be considered when selecting landfill sites to prevent contamination of water sources (Mirzabeygi et al., 2017). The drainage system in Feyzabad includes a network of small streams, wells, and irrigation channels, which are heavily integrated into the agricultural practices of the region (Aghanabati, 2012). As such, any landfill site must be carefully evaluated to ensure that it is not located near these critical water sources, as runoff from the landfill could lead to leachate contamination. Furthermore, the region's hydrological conditions influence the rate at which water is absorbed or flows through the ground, which is an important factor when assessing the potential for groundwater contamination. Understanding the hydrological behavior of the area through GIS-based mapping and environmental monitoring is essential for identifying suitable landfill locations that minimize the risk to the surrounding water resources.

B. Influencing Factors

Selecting an appropriate landfill site in the Feyzabad region involves evaluating a variety of geological, environmental, socio-economic, and technical factors to ensure minimal environmental impact and sustainability. These factors are essential for both the safety of the environment and the well-being of the local communities. Below are the key factors that need to be considered:

Geology and Soil Composition: The geological characteristics of the region play a key role in the suitability of a landfill site. Areas with stable, low-permeability soils, such as clay-rich layers, are preferable for landfill construction because they offer natural barriers to leachate migration, preventing contamination of surrounding soil and groundwater. On the other hand, regions with high permeability or fractured bedrock pose a higher risk of contaminating groundwater. A thorough geological survey should identify areas with stable, compact soils or sedimentary formations, which are most suitable for waste containment and long-term stability.

Hydrogeological Conditions: Feyzabad's proximity to rivers, seasonal streams, and groundwater aquifers is another critical factor to consider. Hydrogeological studies should be conducted to assess the depth of the water table, groundwater flow, and the direction of groundwater movement. Landfills should be located far from water bodies, particularly rivers and groundwater recharge zones, to avoid contamination from leachate. The region's reliance on groundwater for agricultural and domestic use requires special attention to protecting aquifers and water sources from potential pollutants. Additionally, assessing the

drainage patterns in the area is important to prevent surface water contamination through runoff.

Topography and Terrain: The topography of the Feyzabad region significantly influences landfill siting. Areas with flat terrain are ideal for landfill development, as they reduce construction challenges and provide a stable foundation for waste placement. Hilly and mountainous regions can complicate landfill operations due to the difficulty of accessing the site and maintaining stable waste disposal operations. Furthermore, landfills located in elevated areas may increase the risk of water contamination due to surface water runoff. The natural drainage systems of the region must be considered to ensure that water does not flow toward the landfill and cause environmental contamination.

Land Use and Land Cover: Another essential factor is the existing land use/land cover in the area. Landfills should not be located near agricultural land, residential areas, or protected natural reserves, as these areas are sensitive to contamination. In Feyzabad, where agriculture, particularly saffron cultivation, plays a vital role in the economy, landfill sites should be strategically placed to avoid any impact on crop production. Additionally, ecologically sensitive zones should be avoided to minimize damage to local biodiversity and ecosystems. GIS-based spatial analysis can help identify areas where land use compatibility is ideal, ensuring minimal conflict between landfills and other land uses.

Seismic and Environmental Risks: The seismic activity of the region is a significant consideration. As Feyzabad is located in an area prone to earthquakes, it is crucial to choose a landfill site that minimizes the risks associated with earthquake-induced soil displacement or liquefaction. Sites should be assessed for their seismic stability to ensure that waste containment is not compromised in the event of an earthquake. Additionally, climate factors, including the potential for extreme weather events like heavy rains or flooding, must be taken into account. Areas prone to flooding should be avoided to reduce the risk of leachate contamination spreading into surrounding areas.

Proximity to Infrastructures: Landfills must be accessible for waste collection, transportation, and monitoring purposes. Proximity to major roads and transportation infrastructure is essential for cost-effective waste management. However, landfills should not be located too close to urban centers or residential areas due to the potential for odors, air pollution, and visual pollution. In Feyzabad, balancing accessibility with social and environmental impacts is key to identifying a suitable location. It is also important to evaluate the cost of transportation, as landfills located too far from urban areas may increase fuel consumption and greenhouse gas emissions.

Public Health: Public health considerations are vital when selecting a landfill site, especially in areas with dense populations or agricultural communities. Proximity to residential areas should be minimized to reduce risks associated with odor, pests, and disease vectors. Community acceptance is another critical factor. Local populations may resist landfill development due to concerns over environmental risks or perceived health impacts. Involving local stakeholders and conducting community consultations can help address concerns and promote a more transparent and collaborative approach to site selection.

These mentioned factors have been utilized to facilitate the landfill site selection process using the AHP and GIS. Figures 4 to 12 present suitability maps for each of these influencing factors, highlighting the locations that are deemed suitable based on the available data. The dataset used for this analysis includes a 30-meter resolution digital elevation model (DEM) for topography and geomorphology, obtained from global satellite sources. Geological and soil composition data were sourced from the geological survey of Iran (GSI), while seismic activity data were collected from the international institute of earthquake engineering and seismology (IIEES). Additionally, climatological data were retrieved from the Iran Meteorological Organization, and hydrological data, including groundwater and surface water resources, were obtained from the Iran water and wastewater and urban facilities department (ABFA). The results of these mappings were used with AHP to provide a site selection suitability map for landfill. By integrating these datasets into a GIS-based MCDA framework, the AHP method was applied to assign weights to each factor based on their relative influence on landfill site suitability. The final suitability maps indicate the most appropriate locations for landfill development while ensuring minimal environmental impact and compliance with regulatory standards.

III. MATERIALS AND METHODS

The methodology for selecting an appropriate landfill site in Feyzabad, Razavi Khorasan, involves a systematic and multi-step approach, integrating GIS, MCDA, and expert judgment. The first step is the collection of spatial and non-spatial data from various sources, including influencing factors. This data includes soil composition, water resources, topography, land use, seismic activity, and proximity to infrastructure that were implemented in GIS which are used to store, process, and analyze the spatial data, allowing for a spatially explicit representation of the study area. In the next phase, criteria weighting and ranking are performed through the AHP. AHP helps to structure complex decision problems by breaking them into a hierarchy and assigning weightings to various factors based on their importance

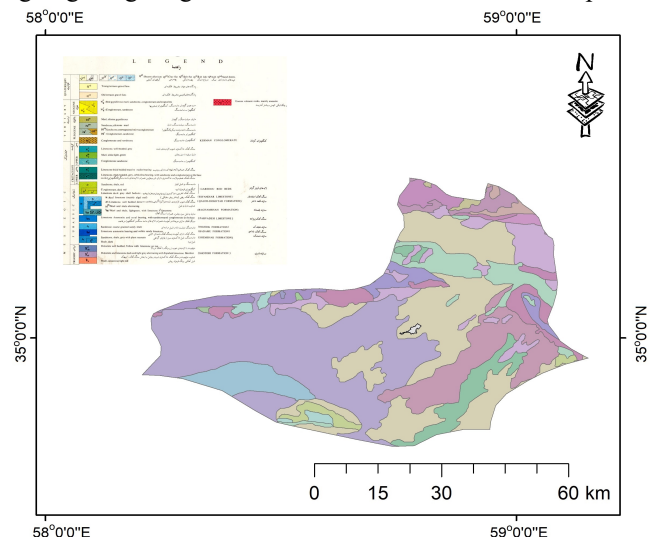


Fig. 4 Suitability map for geology and soil composition (Geological Survey of Iran, 2009)

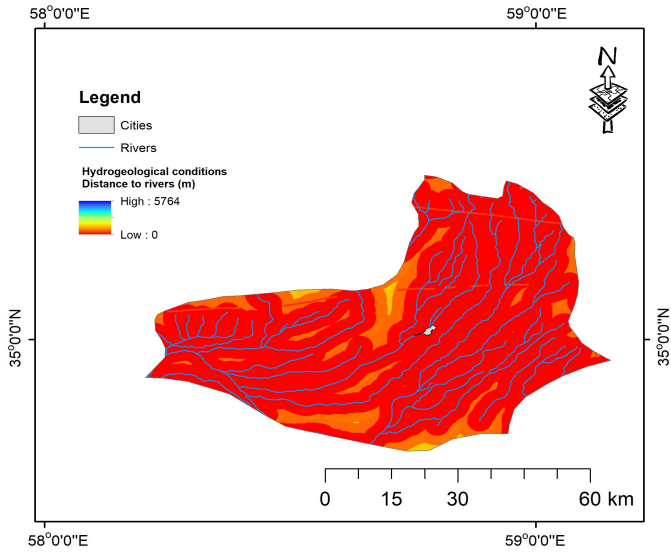


Fig. 5 Suitability map for hydrogeological conditions

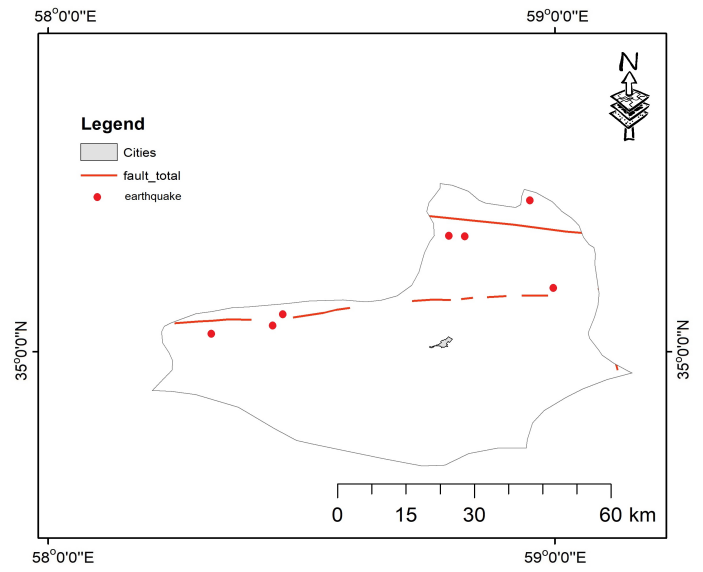


Fig. 8 Suitability map for seismic activities

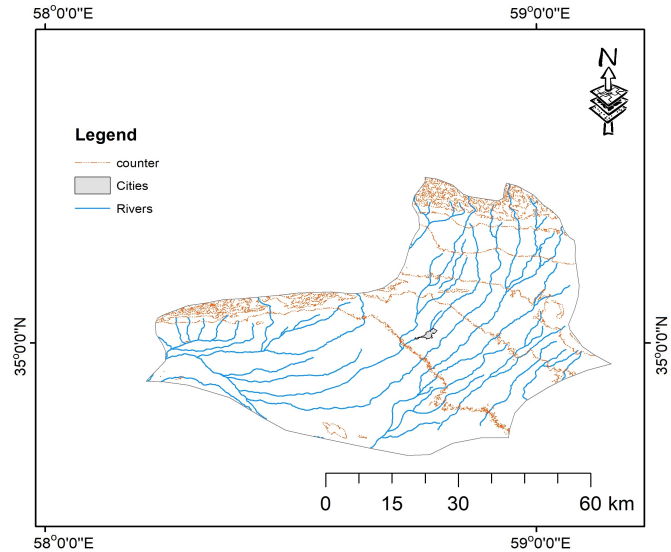


Fig. 6 Suitability map for topography and terrain

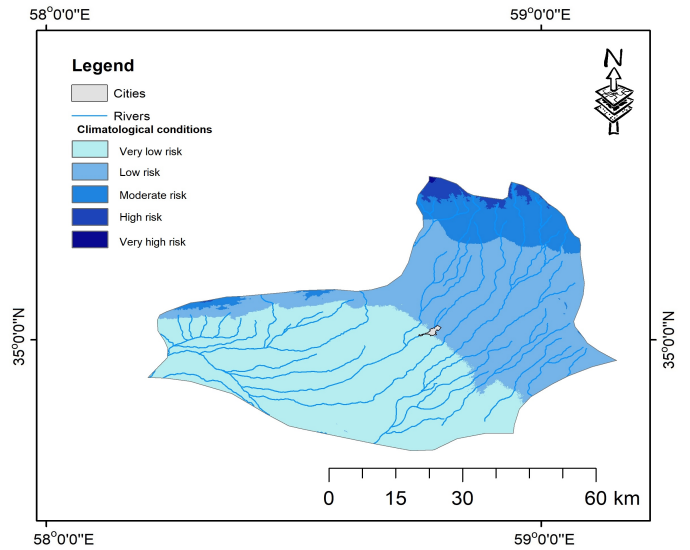


Fig. 9 Suitability map for climatological conditions

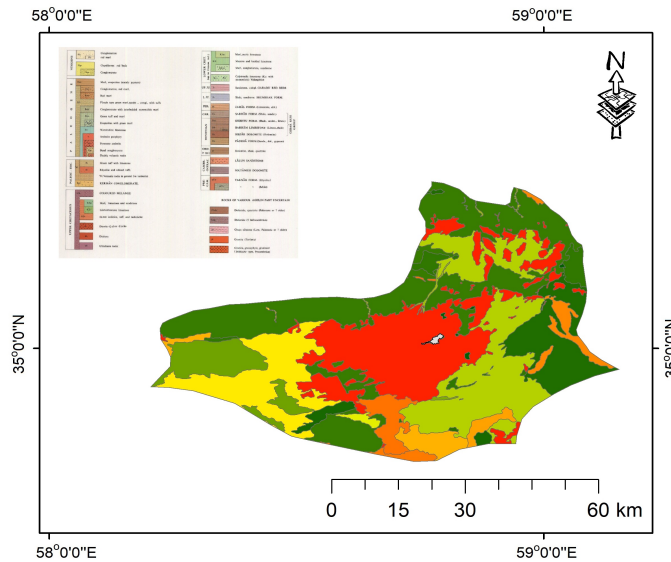


Fig. 7 Suitability map for land use/land cover

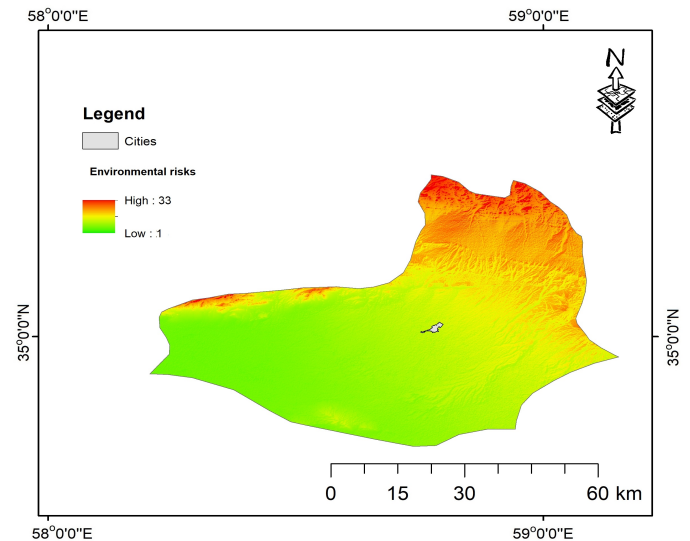


Fig. 10 Suitability map for environmental risks

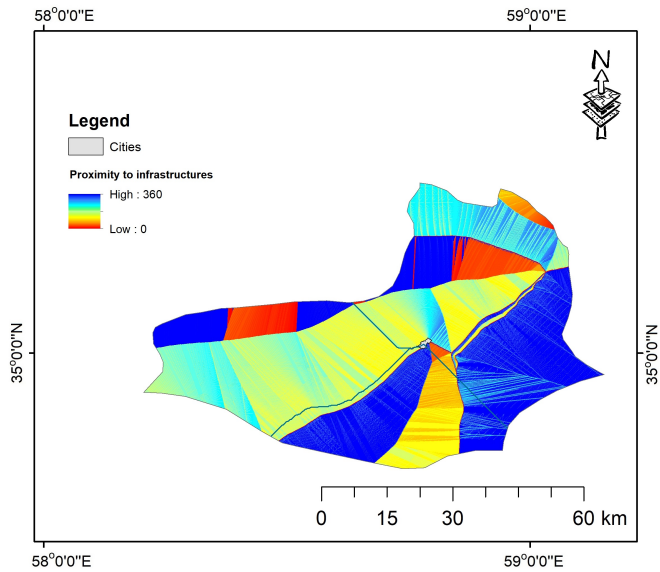


Fig. 11 Suitability map for proximity to infrastructures

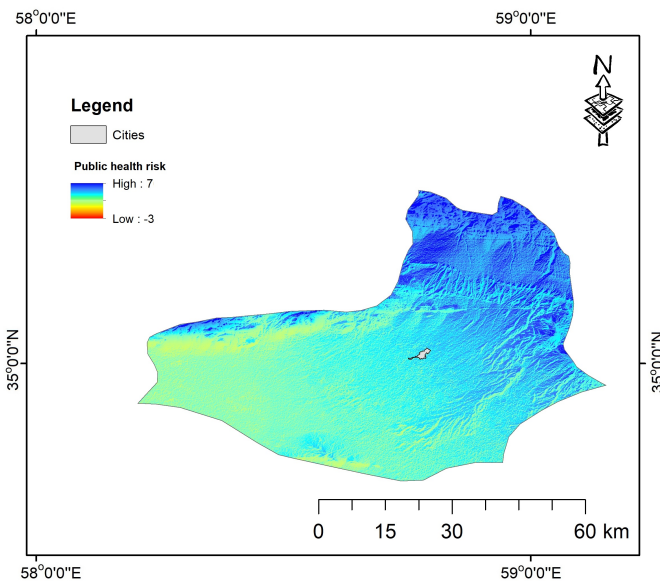


Fig. 12 Suitability map for public health

(Uyan, 2014). Once the criteria are ranked, suitable landfill sites are identified by overlaying the weighted criteria on the GIS map to create a suitability index for each location (Yal and Akgün, 2013). Finally, the best location for the landfill is selected based on the highest suitability scores (Vasiljević et al., 2012). A sensitivity analysis is also performed to check the robustness of the selected site, considering potential variations in the weights and rankings of the criteria (Rabiei-Dastjerdi et al., 2021).

The AHP is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology (de FSM Russo & Camanho, 2015). It provides a comprehensive and rational framework for comparing multiple criteria and alternatives in a decision-making process (Darko et al., 2019). An example of AHP architecture is provided in Figure 13. decomposes the problem into a hierarchical structure consisting of three levels: the goal at the top, followed by criteria and sub-criteria at the intermediate level, and the alternatives at the bottom (Şener et al., 2010). To implement AHP, experts are

asked to compare the relative importance of the criteria and sub-criteria pairwise, usually on a scale of 1 to 9. These comparisons form a pairwise comparison matrix, which is then processed using eigenvalue methods to determine the relative weights of the criteria (Yoshimatsu and Abe, 2006). After assigning weights to each criterion, the alternatives are scored based on how well they meet each criterion (Akbari et al., 2008). These scores are then multiplied by the criteria weights, and the results are summed up to determine the final priority ranking of the alternatives (Ghazifard et al., 2016). AHP is widely used in landfill site selection because it helps to quantify subjective judgments and provides a transparent and consistent decision-making process (Şener et al., 2010).

The implementation of the landfill site selection model in Feyzabad is carried out using ExpertChoice 11 software and GIS tools. Figure 14 provides the process flowchart for this study. The process starts with data collection and preparation in GIS, where spatial layers representing each criterion are created. Each layer is assigned a suitability score, which indicates how well the area meets the criteria for landfill placement. For example, areas with low permeability soil or stable geology are assigned higher scores for the geology criterion, while areas closer to water sources would receive lower scores for the hydrogeology criterion.

In ExpertChoice 11, the next step involves applying the AHP method to assign weights to each criterion based on expert input (Kharat et al., 2016). The software allows for the construction of the pairwise comparison matrix and the calculation of criteria weights. These weights are then used to modify the suitability scores in GIS. Once the criteria weights are integrated, GIS software generates a final suitability map that highlights the most suitable locations for landfill development based on the weighted criteria.

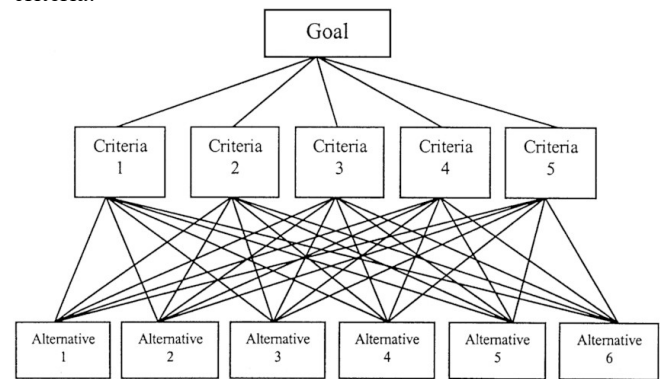


Fig. 13 A general architecture of AHP model (Badri, 2001)

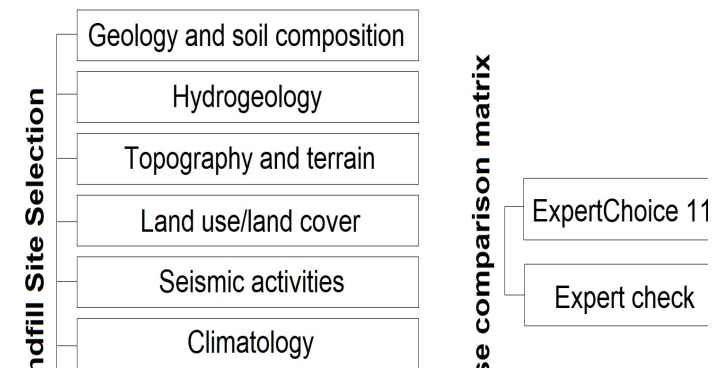


Fig. 14 Flowchart of analysis for this article

The overlay analysis in GIS combines all layers into a single composite index, which is then used to rank the potential sites (Pandiyani et al., 2011). Finally, the sensitivity analysis in ExpertChoice 11 allows the decision-makers to test different weight scenarios and assess how changes in the criteria weights affect the final landfill site selection. This ensures that the selected site is robust and adaptable to varying priorities. After identifying the most suitable location, the model also provides recommendations for mitigating any potential environmental or social impacts based on the site's characteristics. Thus, using ExpertChoice 11 and GIS, the methodology ensures that the selected landfill site in Feyzabad is optimal from both environmental and socio-economic perspectives.

IV. RESULTS AND DISCUSSION

The landfill site selection process in Feyzabad was conducted using AHP and GIS to evaluate multiple influencing factors systematically. Table 1 presents the weighted parameters used in landfill site selection, which were derived from the AHP analysis. The priority weights for these parameters were calculated based on the structured decision-making framework illustrated in Figure 14. The results of the AHP analysis, shown in Figure 15, indicate that geology and hydrology are the most critical factors influencing landfill site selection in the study area. Land use/land cover and topography were identified as secondary factors, as determined by the AHP model and processed using ExpertChoice 11 software. These results were then integrated into GIS to generate a landfill suitability map, which is provided in Figure 16. Further analysis of Table 2, published by the Feyzabad City Hall, reveals that the majority of the waste generated in the region exceeds the provincial waste generation standard, highlighting the urgent need for proper waste management and landfill facilities. The dominant type of waste is household waste, which produces leachate with high pollution potential and is highly biodegradable. If not properly managed, this waste could pose severe threats to environmental health and water resources, particularly groundwater. Moreover, statistical analysis indicates that waste generation per capita and per city is projected to increase in the near future, making the development of a modern landfill site essential to prevent environmental degradation and public health risks.

According to land use/land cover data provided in Table 3, Feyzabad's dominant land coverage consists of agricultural land, with urban expansion primarily occurring in the south and southwestern regions. The presence of mountainous terrain in the northern parts and an anticline structure in the northwest imposes significant constraints on urban expansion. These geographical features limit potential landfill site options in certain areas and necessitate careful consideration of topographical and geological factors during site selection. Additionally, geological and hydrological maps of the study area indicate that the main water resources, including permanent and seasonal rivers, originate from these mountainous regions. This further reinforces the need to avoid landfill placement near water sources to minimize contamination risks. The study highlights the dominant role of geological and hydrological factors in landfill site selection. Areas with low permeability soil, stable geological formations, and a safe distance from groundwater recharge zones were

identified as the most suitable locations. The AHP analysis confirmed that geology and hydrology received the highest priority weights due to their direct influence on groundwater contamination risks and land stability. This finding aligns with previous studies, which emphasize that proper site selection should prevent leachate infiltration and ensure long-term waste containment.

The increasing waste generation rate in Feyzabad, which exceeds provincial standards, indicates that the city requires modernized waste management solutions. Household waste, which constitutes the majority of waste production, has high organic content that leads to significant leachate formation. If improperly handled, this leachate could contaminate groundwater aquifers, especially given the hydrogeological characteristics of the region. The statistical projections suggest that landfill capacity should be designed to accommodate future increases in waste volume, requiring proper engineering measures such as leachate collection systems and waste compaction technologies. The land use/land cover analysis reveals that Feyzabad's urban expansion is concentrated in the southern and southwestern parts, while the northern mountainous terrain and anticline structures restrict further development. This suggests that landfill siting must avoid highly urbanized zones and productive agricultural lands while considering topographical constraints. The GIS analysis allowed for an efficient identification of less populated, non-agricultural, and geologically stable areas for landfill placement. This approach ensures that the site selection minimizes land-use conflicts and environmental disturbances.

Given that Feyzabad's primary water resources originate from the mountainous areas, special attention must be given to hydrological risks when determining landfill locations. The seasonal and permanent rivers flowing from these areas make them highly sensitive to pollution, reinforcing the importance of selecting landfill sites that are sufficiently distant from surface and groundwater sources. The results confirm that placing a landfill downstream from key water recharge zones would significantly reduce the risk of leachate contamination and protect local water supplies. The combination of GIS and AHP methodologies proved to be an effective decision-making tool for landfill site selection. GIS enabled the spatial analysis and visualization of multiple criteria, while AHP provided a structured and objective approach to weighting the importance of each factor. The use of ExpertChoice 11 software allowed for the pairwise comparison of factors, ensuring a transparent and scientifically validated weighting process. The integration of these tools resulted in the development of a comprehensive landfill suitability map, which serves as a valuable resource for urban planners and environmental policymakers.

Table 1 Hierarchical model of landfill site selection of Feyzabad

Goal	Influencing factors	Weights	CR value	Results
Landfill site selection	Geology	0.232	0.071	Suitable
	Hydrology	0.124	0.082	Unsuitable
	Topography	0.120	0.055	Suitable
	Land use/land cover	0.109	0.062	Unsuitable
	Seismicity	0.100	0.046	Suitable
	Climatology	0.075	0.077	Suitable
	Environmental risks	0.062	0.032	Suitable
	Proximity to infrastructure	0.017	0.018	Suitable
	Public health	0.061	0.012	Unsuitable

Table 2 The results of urban management and municipal waste studies in Feyzabad

No.	Parameters	Outcome	Considerations
1	Effective radius	25 km	-
2	Term interest in the landscape	40 year	-
3	Current population	19,129 p	-
4	Expected population growth	3.1%	Statistical analysis
5	Waste production capita (person per day)	850 gr	
6	Waste production capita (city per day)	160 ton	
7	Waste produced (person per year)	352.25 km	
8	Waste produced (city per year)	63120 ton	
9	Waste compounds	Mostly household	Field surveys and field observations
10	Type and concentration of waste		
11	Leachate produce ability	Yes	
12	Terms of leachate	Bio-organic, saline	Leachate chemical tests
13	Environmental effects	High pollution potential	
14	Waste transportation	Vehicle and Garbage truck	-
15	Landfill final use	Traditional dump and unsuitable	Large-scale land subsidence

Table 3 Levels and information of land use/land cover in Feyzabad

Parameters	City Hall authority (hectares)	Area of County (%)	Area of province (%)	Total involved area
Forest and woodlands	0.0	0.00	0.00	0.00
Dense pastures	3325.75	7.20	6.93	3201.54
Semi-dense pastures	3745.82	8.11	8.06	3721.58
Agricultural lands	9295.22	20.13	22.94	10591.58
Dry farming	2957.12	6.40	5.95	2745.19
Irrigated farming	1558.26	3.37	2.19	1013.44
Gardens	3599.25	7.80	7.67	3540.13
Residential areas	1266.55	2.74	1.41	1652.31
Watershed	739.63	1.60	0.01	659.66
Industrial areas and facilities	3080.09	6.67	6.28	2897.42
Barren and unused areas	6922.77	14.99	16.58	7654.55
Lagoon	1095.81	2.37	0.95	440.94
Land without data	8585.93	18.60	21.04	9713.50
Total	46172.2	100	100	47831.48

**Priorities with respect to:
Landfill**

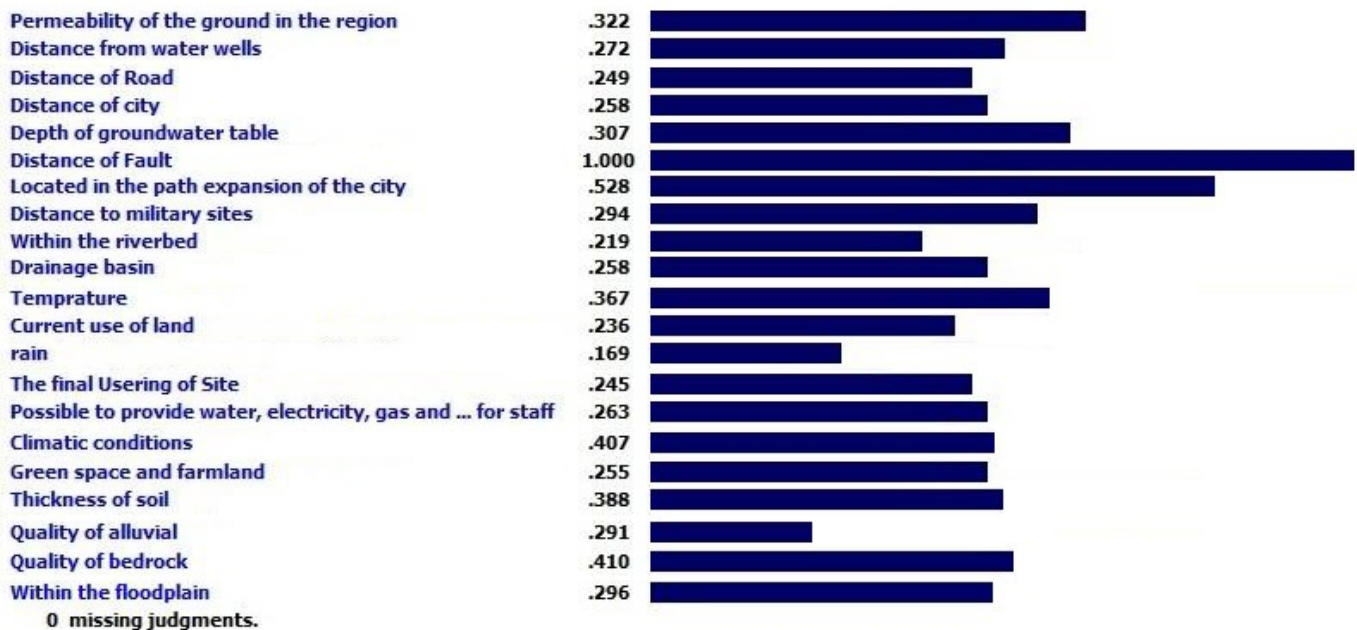


Fig. 15 Results of Feyzabad landfill site selection with ExpertChoice 11

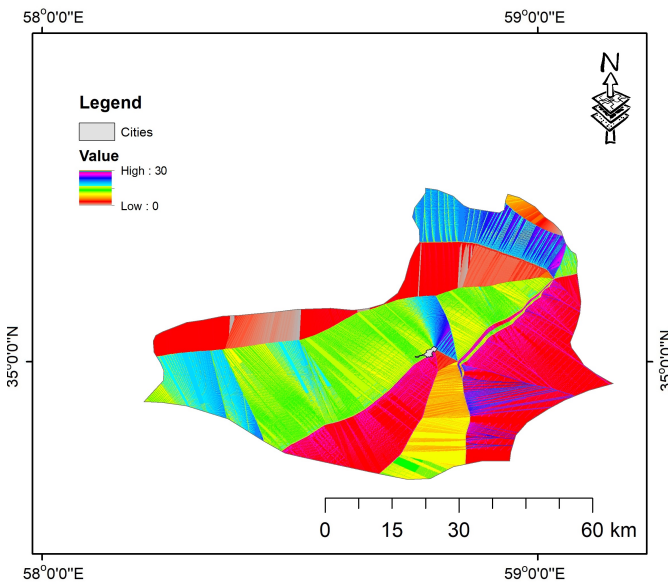


Fig. 16 Landfill site selection suitability map

V. CONCLUSION

The selection of a suitable landfill site is a critical process that requires a comprehensive assessment of geological, environmental, socio-economic, and technical factors. This study utilized a GIS-based MCDA approach, incorporating the AHP to systematically evaluate the suitability of different locations for landfill development in Feyzabad, Razavi Khorasan. By integrating various datasets, including topography, geology, hydrology, climate, seismic activity, and land use, this research identified the most optimal sites while minimizing potential environmental and social risks. The results demonstrated that areas with low permeability soils, stable geology, sufficient distance from water sources, and accessibility to transportation networks were the most suitable for landfill placement. The suitability maps generated in this study provide a scientifically grounded decision-making tool for urban planners and environmental authorities, ensuring that waste disposal activities do not compromise groundwater quality, ecosystem stability, or public health. Furthermore, the use of ExpertChoice 11 software for AHP calculations allowed for an objective weighting of criteria, ensuring that all relevant factors were proportionally considered. The application of GIS spatial analysis enabled precise mapping and visualization of potential landfill locations, offering a data-driven approach to sustainable waste management planning. In conclusion, this study highlights the effectiveness of AHP and GIS-based methodologies in landfill site selection and underscores the importance of integrating scientific data with policy-driven decision-making.

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AUTHORS' CONTRIBUTIONS

Alireza Yosefian, and Hamed Mahmodi conducted the main data analysis, contributed to the data collection, preprocessing, and interpretation, and were

responsible for drafting the initial manuscript. Hamed Mahmodi and Alireza Yosefian performed checks, supervision, conceptual guidance, and critical revision of the manuscript. All authors read and approved the final manuscript.

CONFLICT OF INTEREST

The authors have not disclosed any competing interests.

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