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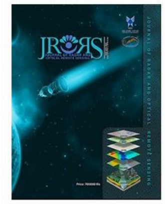

Optimal Site Selection of Construction Sites Using Fuzzy AHP in GIS (Case Study: Yazd City)

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ABSTRACT

Objective: With the rapid growth of urbanization and the increase in construction projects within urban areas, selecting appropriate locations for construction sites has become a critical issue in urban planning. This study aims to determine the optimal locations for construction sites in Yazd city by integrating the Analytic Hierarchy Process (AHP) with fuzzy logic analysis within a GIS environment.

Methods: After identifying and assigning weights to eight key criteria (such as distance from medical centers, educational institutions, industrial areas, roads, and natural resources), information layers were prepared and integrated using fuzzy membership functions and spatial overlay analysis.

Results: The results revealed that the eastern and southern zones of Yazd, especially areas adjacent to transportation networks and industrial zones, are the most suitable for workshop establishment. In contrast, densely populated urban areas with sensitive land uses were deemed inappropriate.

Conclusion: The findings of this research can serve as an efficient model for spatial decision-making in construction projects, especially in historically and architecturally sensitive urban areas.

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Introduction

Problem Statement: With the increasing urban population and the expansion of construction projects, optimizing the location of construction sites has become one of the fundamental issues in urban construction management. Improper site selection for these workshops can lead to increased transportation costs, urban traffic disruption, resident dissatisfaction, and environmental damage (Sebt et al., 2008).

Related Work: On the other hand, the use of modern analytical tools such as Geographic Information Systems (GIS) enables precise spatial analysis, data integration, and informed decision-making (Masoudi and Jokar, 2015). GIS, with its capability to integrate spatial and descriptive data, provides a framework for modeling influential factors in site selection, such as access to transportation networks, distance from residential areas, proximity to material sources, land slope, and land-use compatibility. Previous studies have shown that combining GIS with multi-criteria decision-making methods such as AHP or fuzzy methods significantly enhances the accuracy and reliability of site selection (Hadipour, 2014). GIS and multi-criteria decision-making models enable simultaneous evaluation of various factors affecting workshop location. GIS can integrate spatial, environmental, and operational data, providing a scientific and accurate framework for analyzing information layers such as land use, population density, transportation access, distance from sensitive areas, topography, and more (Karami et al., 2020). In addition, decision-making models such as AHP and Fuzzy-AHP can assign weights to criteria and prioritize options under complex, multi-factor conditions (Ebrahimi and Maleki, 2022).

Research Gap: In Iran, despite some studies on locating industrial and service facilities, there has been limited attention to urban construction sites site selection. In Yazd, with its rapid construction growth in recent decades and its historically valuable urban fabric, careful selection of site locations requires attention to environmental, structural, and operational criteria (Rahmani et al., 2020). The rapid urban population growth, increasing number of construction projects, and spatial and resource limitations in Iranian cities—particularly those with historical urban fabrics like Yazd—necessitate the optimal management of resources and urban construction activities. Construction workshops, which play a vital role in storing materials, housing equipment, and supporting construction operations, are key elements in this process. However, poor site selection of these workshops can lead to various issues, including noise pollution, traffic disruption, infrastructure damage, and public dissatisfaction (Niroumand et al., 2022). In many urban projects across the country, site selection is often based on convenience or ownership limitations, without analytical support, leading to project inefficiencies and increased social and environmental conflicts (Rahmatabadi and Sarrafi, 2023). This issue is even more critical in cities like Yazd, known for their unique cultural, historical, and physical attributes, where inappropriate workshop locations can harm the historic fabric or disrupt tourism (Ahmadi et al., 2021). Despite the importance of this issue, few studies in Iran have scientifically and precisely addressed construction site's location within a GIS framework, especially in historic cities like Yazd. The current gap in applied research and the urgent need of executive institutions for a scientific model underline the necessity of conducting focused research in this area.

Research Background

Wefki et al. (2025), in a study aimed at improving the selection process of excavation support systems in building projects, employed the Fuzzy AHP multi-criteria decision-making model. The findings indicated that applying fuzzy approaches in uncertain conditions and high-risk construction environments leads to more accurate decision-making and reduces human errors. Although the study focused on excavation support systems, its methodology—particularly the fuzzy multi-criteria analysis structure—is adaptable to the problem of construction site location in complex urban contexts.

Mustafa et al. (2024), in a study, examined the integration of Geographic Information Systems (GIS), fuzzy logic, and the Adaptive Neuro-Fuzzy Inference System (ANFIS) model to assess optimal dam site selection in a water supply project for the city of Halabja. The findings revealed that the combined GIS-Fuzzy-ANFIS model, compared to traditional methods, provides higher accuracy in evaluating location options and demonstrates high efficiency when dealing with imprecise or uncertain data.

Wang et al. (2023) applied a combined AHP and GIS method for construction site selection in urban China (Beijing), highlighting the importance of public transport proximity and minimizing urban disruption. Jafari et al. (2023) investigated the application of GIS in the location of urban construction sites in Tehran. Using the AHP model in a GIS environment, they showed that proximity to the project, distance from residential areas, and access to main roads are significant criteria.

Yousefi and Ahmadi (2022) used the FAHP model and GIS to analyze optimal site selection for construction projects in Mashhad. Their findings demonstrated the high potential of multi-criteria decision-making models in location prioritization. Ali and Al-Harbi (2022) used the Fuzzy-AHP model and GIS in Saudi Arabia to locate construction project workshops optimally, showing that fuzzy logic enhances decision accuracy under uncertainty. Ghanbari and Salehi (2021) studied the spatial analysis of temporary urban land uses, including construction sites, using spatial models in GIS, focusing on Isfahan and offering suggestions for urban space management. Taheri and Razavi (2020) discussed the environmental impacts of improper construction sites locations and emphasized the necessity of GIS in spatial planning for urban projects.

Kazemi and Mousavi (2020) applied a combination of AHP and GIS for the optimal location of temporary land uses in Tabriz, concluding that considering environmental and infrastructural data leads to more accurate results.

Sajjadi et al. (2019) emphasized the integration of economic, environmental, and social criteria in site selection processes for construction sites in Shiraz, highlighting the role of spatial analysis tools in reducing public dissatisfaction. Kumar et al. (2021) conducted a study titled GIS-based Site Selection for Temporary Construction Facilities in India, stressing the importance of integrating land and demographic data for optimal site selection.

Demirel et al. (2020) used the ANP model and GIS in Turkey to assess suitable locations for construction sites in infrastructure projects, underlining the importance of proper criteria weighting in spatial modeling. Chen & Zhang (2020) employed a Spatial Decision Support System (SDSS) based on GIS for locating construction sites in Shanghai, showing that such systems can facilitate collaboration among management bodies.

Research Methodology

Figure 1, Shows the workflow diagram of the present study.

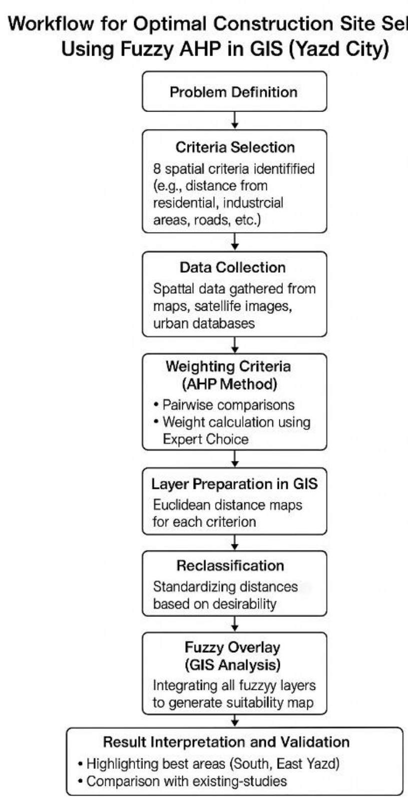

Figure 1. Workflow diagram.

Study Area

Yazd Province, with an approximate area of 131,551 km², is located in the central plateau of Iran, between 29°52' and 33°27' north latitude and 52°55' to 56°27' east longitude. According to the latest administrative divisions, Yazd consists of 9 counties, 19 cities, and 43 rural districts. The province lies adjacent to the Salt Desert in central Iran and is bordered by Isfahan to the northwest and west, Khorasan to the northeast and east, Kerman to the east and southeast, and Fars to the southwest. The provincial capital sits at an altitude of 1,215 meters above sea level and is located 508 kilometers by air from Tehran (Yazd Comprehensive Plan, 2016). Yazd Province has 10 counties (Yazd, Abarkouh, Ardakan, Bafq, Taft, Khatam, Saduq, Tabas, Mehriz, and Meybod), 23 cities, 20 districts, and 51 rural districts. It shares borders with Semnan to the northwest, Isfahan to the west, Fars to the southwest, South Khorasan to the east, Razavi Khorasan to the northeast, and Kerman to the east and southeast. Yazd County is the second most significant "adobe" and "historical" city in the world. It spans 2,491 km² and includes two districts (Central and Zarch), along with the cities of Yazd, Hamidiya, Shahdiya, Zarch, and rural districts such as Fajr, Fahraj, Allahabad, and Mohammadabad. The estimated population of Yazd city in 2019 was 557,634. The city's history dates back 8,000 to 12,000 years. Historically known as Isatis and Katteh, Yazd is also referred to as "The City of Windcatchers," "The City of Bicycles," and "The Abode of Worship" (Yazd Municipality Website). Figure 2, shows the geographical location map of the study area.

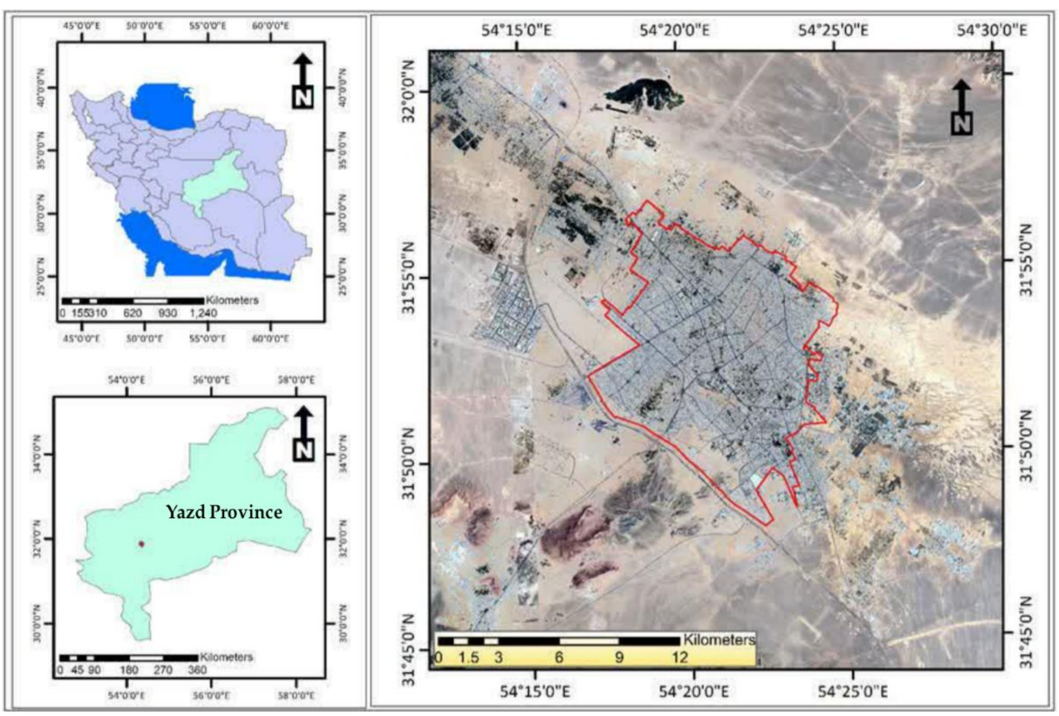

Figure 2. Geographical location of the Study Area (Yazd City).

Research Methodology

This study is applied in terms of its aim and descriptive-analytical and spatial in terms of its nature and methodology. Part of the theoretical information was collected through library research, including documents, reports, and relevant theses. Based on these studies, appropriate indicators and methods for their assessment were determined. To identify the optimal locations for construction sites in the city of Yazd, a set of eight influential criteria were identified through literature review and consultation with 20 domain experts in the fields of urban planning and spatial analysis. These criteria include distance from:

1. Medical centers
2. Educational centers
3. Residential areas
4. Industrial centers (e.g., industrial towns, factories, workshops)
5. Roads
6. Railway lines
7. Water sources
8. Environmentally sensitive areas (e.g., parks and green spaces)

To determine the relative importance of each criterion, the Analytic Hierarchy Process (AHP) was employed. A pairwise comparison matrix was designed and analyzed using Expert Choice software, resulting in the final weight assigned to each criterion. Next, a distance map for each selected criterion was created using the Euclidean Distance tool. To standardize distance values and enable layer integration, the Reclassification process was applied based on spatial desirability logic. For instance, for criteria such as proximity to medical and residential centers, greater distances were considered more desirable due to reduced disturbance. The reclassified distance layers were then fuzzified using the Fuzzy Membership tool. Afterward, the reclassified distance layers entered the fuzzification stage. Using the *Fuzzy Membership* tool, each layer was assigned a suitable membership function—either Small (Triangular Decreasing) or Large (Triangular Increasing)—based on the nature of the criterion. The triangular functions were selected due to their simplicity in definition, ease of direct interpretation, and widespread use in the literature when dealing with imprecise data. Each layer was assigned an appropriate membership function—Small or Large—based on the nature of the criterion. Subsequently, using the Fuzzy Overlay tool, which employs the OR and Gamma operators, the final integration of the fuzzy layers was carried out, resulting in the generation of the final site suitability map. Finally, the fuzzy output was classified into five categories ranging from *"Relatively Unsuitable"* to *"Highly Suitable"* to facilitate interpretation and analysis. This final map was used as the optimal site selection output for construction workshops in the city of Yazd.

Table 1 presents the final set of criteria, sub-criteria, and zoning information as derived through AHP based on expert input.

Table 1. Final Criteria, Sub-Criteria, and Zoning Using the AHP Method

No.	Main Criterion	Sub-Criterion / Explanation	Effect Type	Final Weight
1	Distance from medical centers	Proximity causes disturbance; sufficient distance is required	Negative	0.080
2	Distance from educational centers	Due to noise and congestion, distance is necessary	Negative	0.075
3	Distance from residential areas	To avoid disturbance and potential pollution	Negative	0.110
4	Proximity to industrial centers	For quick access to materials and machinery	Positive	0.240
5	Proximity to roads	Facilitates easier transportation	Positive	0.220
6	Proximity to railways	For freight and heavy equipment transport	Positive	0.140
7	Distance from water sources	To prevent pollution of water resources	Negative	0.075
8	Distance from sensitive natural areas	Such as parks and vulnerable ecological zones	Negative	0.060

In this table, a positive effect means that the closer a site is to the criterion, the more suitable it is. A negative effect indicates that greater distance from the criterion is more desirable.

Results

In the AHP method, the goal, criteria, and alternatives were clearly defined. The objective was to identify suitable locations for construction sites in Yazd, based on expert evaluations in civil engineering, urban planning, and spatial management. The selected criteria included proximity to industrial zones, water sources, roads, residential areas, educational and medical centers, and green spaces. Using a fuzzy modeling approach, the final suitability map for locating construction sites in Yazd was generated. The results of the fuzzy layer overlay showed that the study area exhibits a relatively narrow range of suitability values. In Figure 11, where the OR operator was used, the final fuzzy map values ranged from 0.930 to 0.999, indicating a generally high suitability across the city based on the selected criteria. However, meaningful spatial differences were still observed within this range. The final suitability map, classified into five categories—from "Relatively Unsuitable" to "Highly Suitable"—revealed that areas in the southeast, northwest, and urban fringes of Yazd were the most appropriate for establishing construction sites. These areas benefit from adequate distance from residential, educational, and medical zones, while maintaining good access to transportation networks and nearby industrial facilities. In contrast, central areas with a high density of sensitive land uses (e.g., medical, residential, educational) were categorized as less suitable for workshop placement. According to the AHP-derived weights, the most influential criteria were:

1. Distance from residential areas
2. Distance from medical centers
3. Proximity to roads

Criteria such as distance from water sources and sensitive natural areas had less impact.

The fuzzy-weighted overlay allowed for a comprehensive spatial analysis, demonstrating that zones balancing constraints and opportunities were given the highest priority. Following this, fuzzified maps for each criterion were developed to visualize their spatial influence and suitability patterns. To compare the output map generated by Fuzzy Overlay, the Gamma function with a value less than 0.5 was also applied, and the resulting map was presented in Figure 12. The value of the final map obtained using the Gamma 0.5 operator ranges from a minimum suitability value of 0.01 to a maximum suitability value of 0.062, indicating the spectrum of spatial suitability across the study area. The output of this process was also classified into five categories - Relatively Unsuitable, Moderate, Relatively Suitable, Suitable, and Highly Suitable - using the Natural Breaks classification method. Given the sensitivity of educational environments and the need for a calm atmosphere conducive to learning, construction sites should be located away from educational institutions to prevent noise pollution and traffic disturbances. Figure 3, displays the fuzzified map of educational areas in Yazd city, illustrating spatial suitability levels based on distance from schools, universities, and other educational facilities. Areas farther from these centers are considered more appropriate for workshop establishment, in line with spatial desirability and urban planning principles.

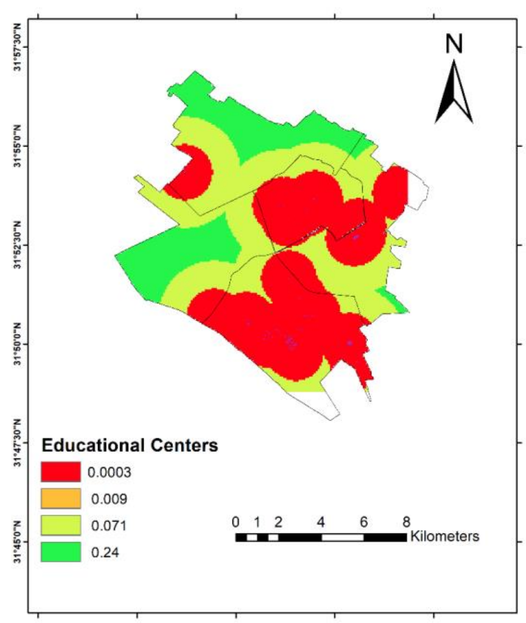

Figure 3. Fuzzified Map of Educational Centers.

According to expert opinions and study findings, it is essential to maintain a sufficient distance from residential areas to prevent noise pollution, dust dispersion, and other disturbances that may compromise the well-being of residents. Figure 4 presents the fuzzified map of residential zones in Yazd city, highlighting areas where greater distance from housing developments is considered more suitable for the placement of construction sites. This approach ensures the comfort and quality of life for urban inhabitants while supporting sustainable site planning.

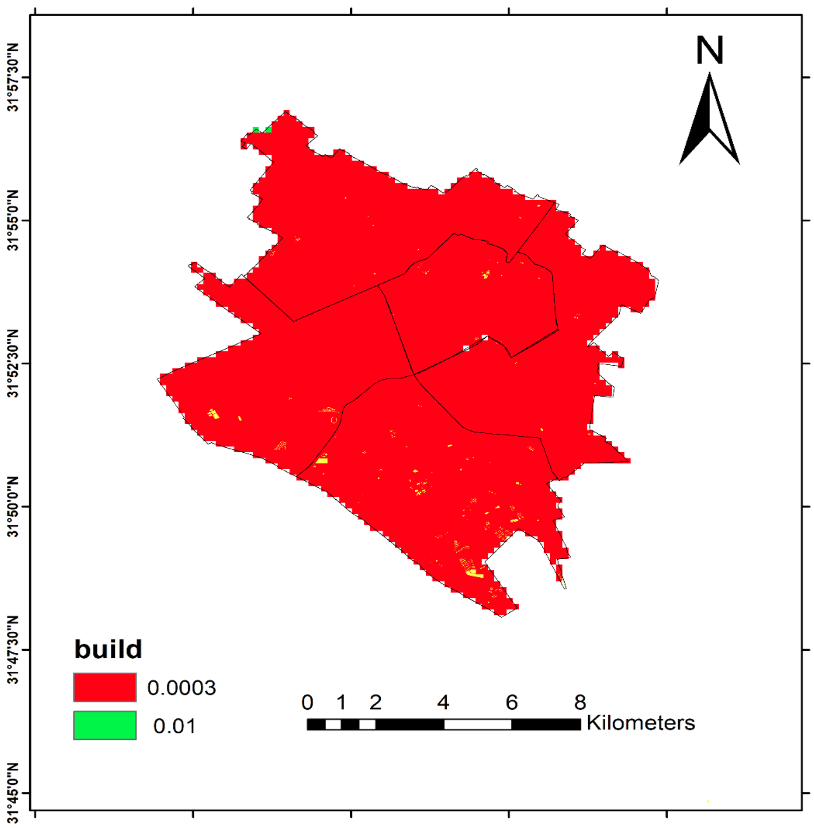

Figure 4. Fuzzified map of residential areas.

As shown in Table 1, in order to minimize noise disturbances and preserve a calm environment for patients, construction sites must be located at a sufficient distance from medical centers. This prevents any interference with the proper functioning of these facilities. Figure 5, presents the fuzzified map of medical zones in the study area.

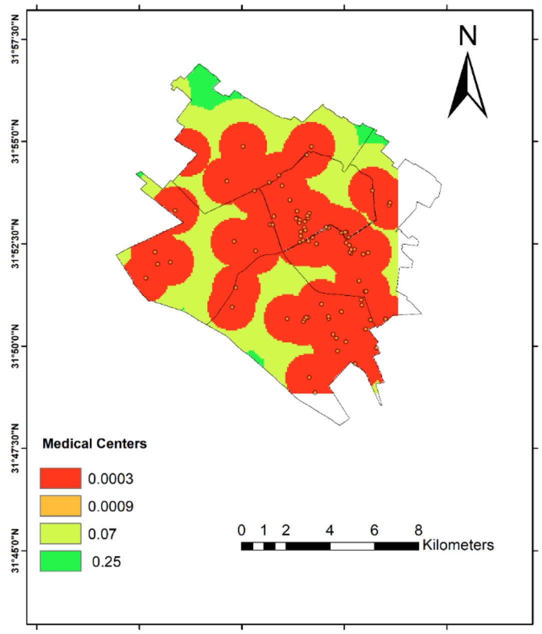

Figure 5. Fuzzified map of medical centers.

To protect natural ecosystems and prevent damage to vulnerable ecological zones, construction sites should be situated at a safe distance from these areas. Figure 6, illustrates the fuzzified map of green spaces and parks within the city of Yazd.

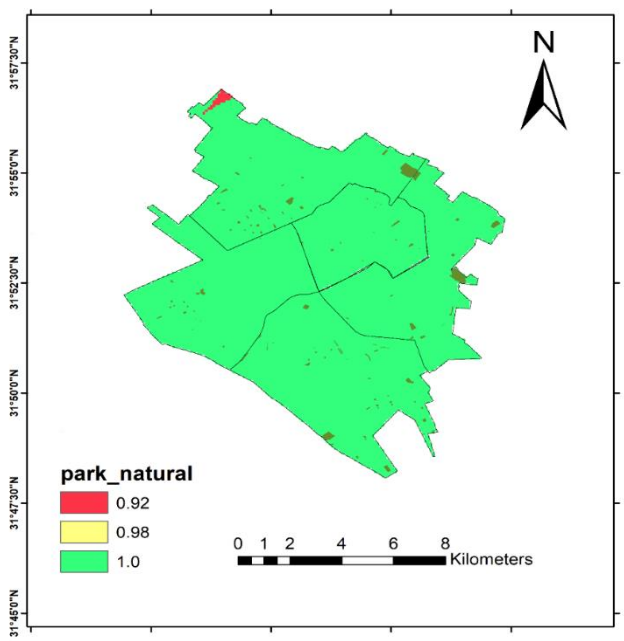

Figure 6. Fuzzified map of green and environmentally sensitive areas

As noted in Table 1, the railway network serves as a cost-effective and efficient freight transport route, especially for heavy machinery and bulk construction materials. Thus, closer proximity to railway lines enhances site suitability. Figure 7, displays the fuzzified railway map for the study area.

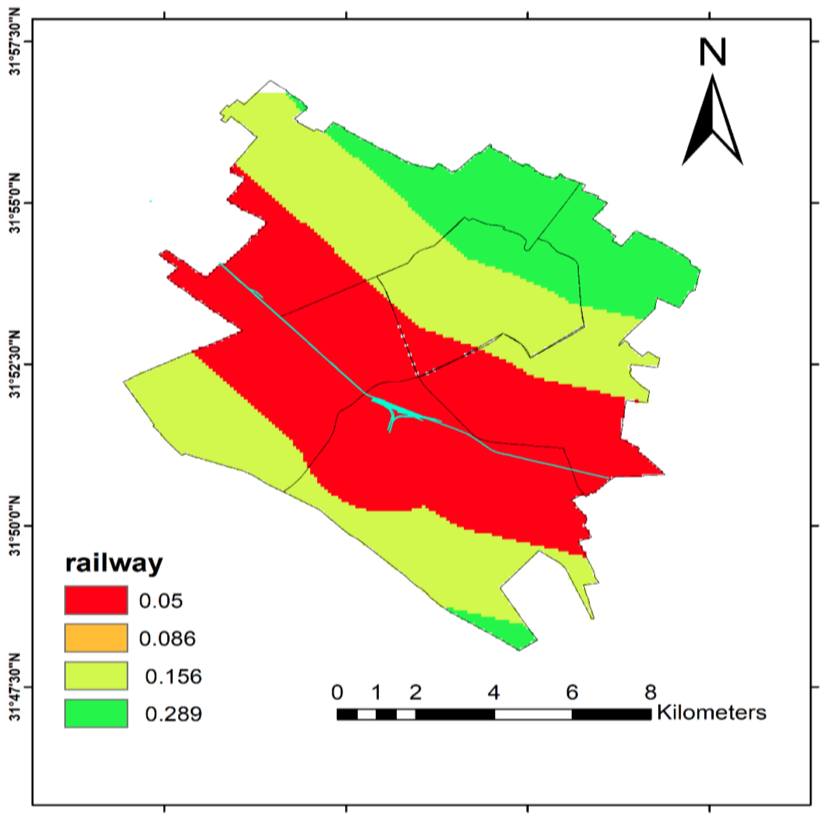

Figure 7. Fuzzified map of railways

Figure 8, shows the fuzzified road network map of the study area. Roads and highways are among the most critical criteria for construction site selection, as they facilitate the transportation of materials and equipment. Easy access to both main and secondary roads can significantly reduce transport costs and time.

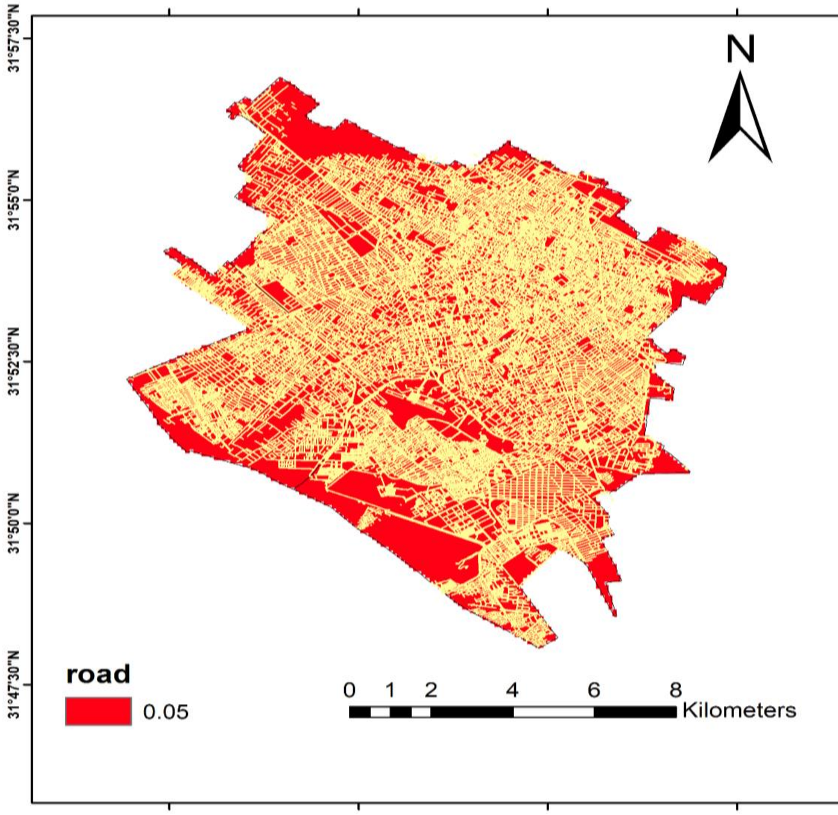

Figure 8. Fuzzified map of roads

Proximity to industrial zones and related facilities accelerates project execution by ensuring quick access to necessary resources and equipment. Therefore, adjacency to industrial areas is a key advantage in construction site selection. Figure 9, depicts the fuzzified map of industrial zones in Yazd.

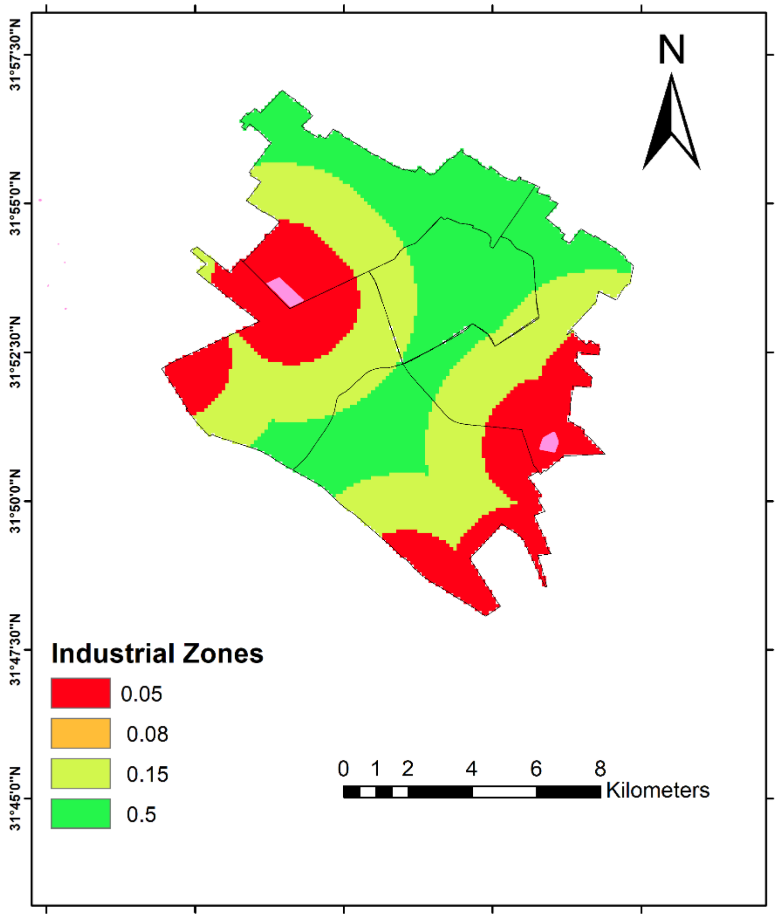

Figure 9. Fuzzified industrial zones map.

To prevent contamination of water sources and maintain environmental quality, construction sites must be located at a safe distance from rivers, springs, and other water bodies. Figure 10, presents the fuzzified water resource map in the study area.

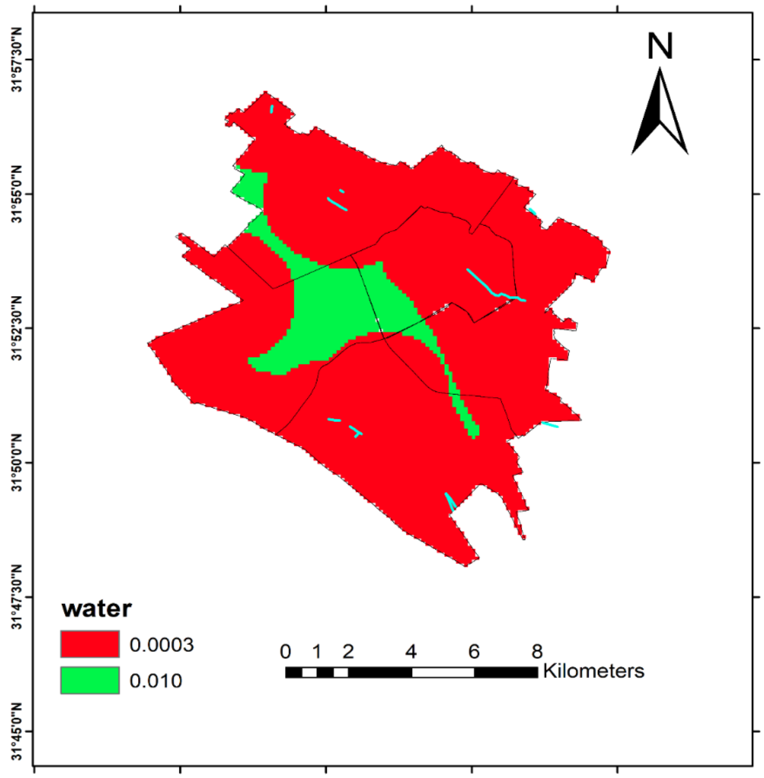

Figure 10. Fuzzified water resources map.

Figure 11, illustrates the final output map of the study, representing the optimal locations for establishing construction sites in Yazd. The map is classified into five categories: Very Suitable, Suitable, Moderately Suitable, Moderate, and Relatively Unsuitable.

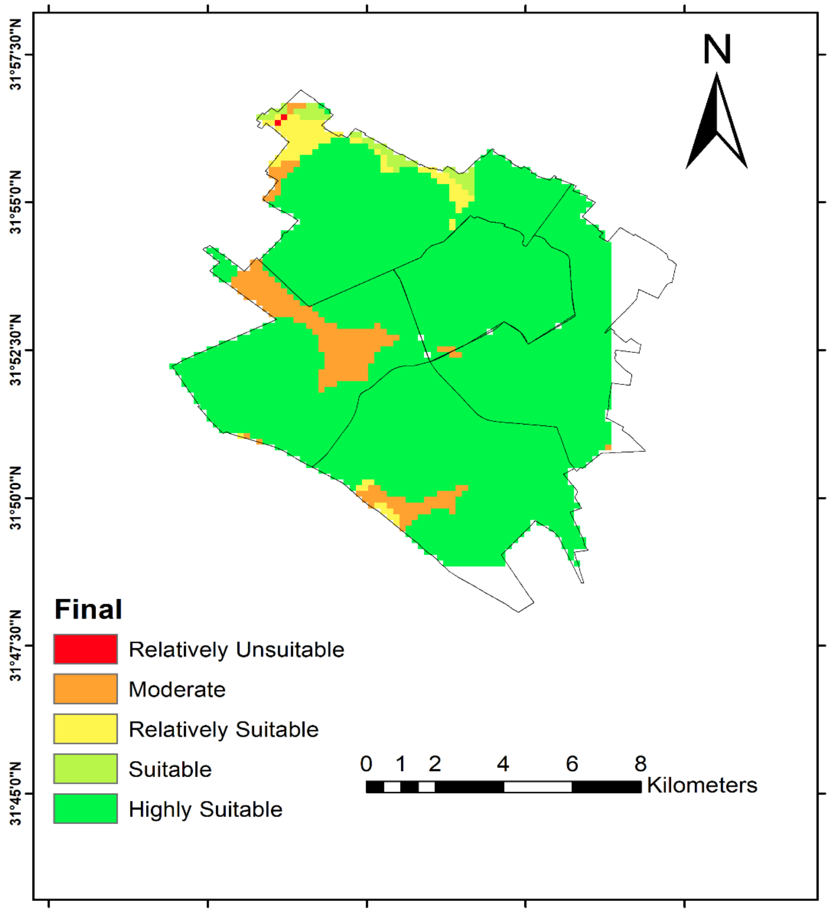

Figure 11. Final suitability map.

In Figure 12, the final map of the study generated using the fuzzy overlay with a gamma operator of 0.5 is presented, illustrating the optimal site selection for construction workshops in Yazd city. The classification includes five categories: Highly Suitable, Suitable, Relatively Suitable, Moderate, and Relatively Unsuitable areas.

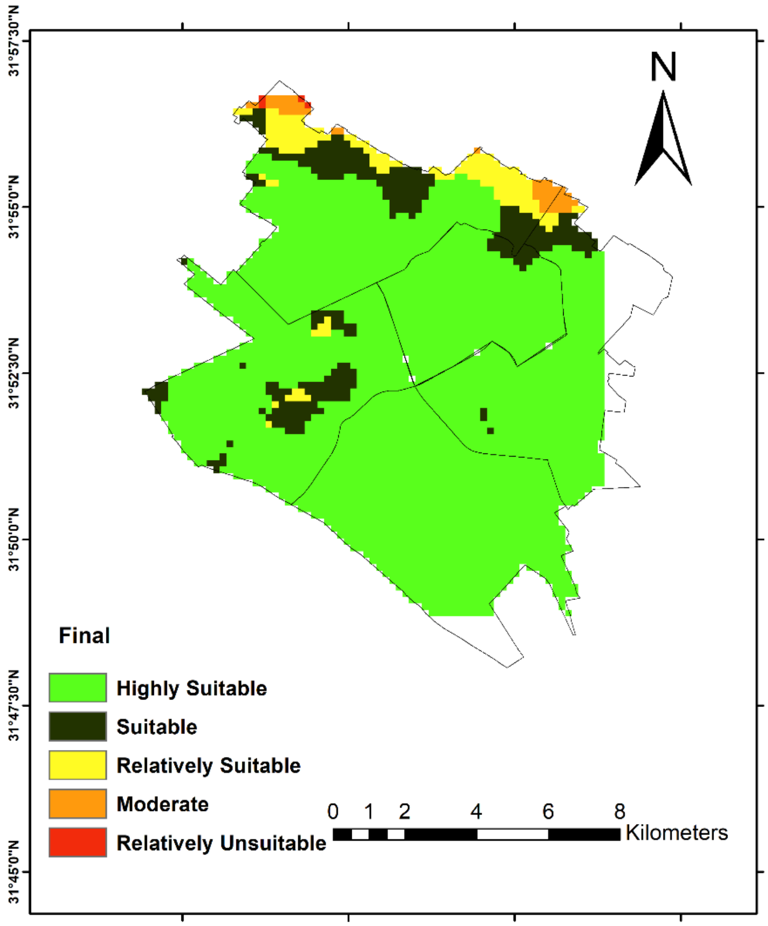

Figure 12. Final suitability map

In the final map derived using the Gamma function with a value of 0.5, the results are categorized as follows:

1. Highly Suitable – Represented by light green: These areas occupy the largest portion of the map and are mainly located in the central and southern parts of the city. Their high suitability is attributed to proper access to infrastructure and distance from sensitive zones such as residential and educational areas.

2. Suitable – Shown in dark green: Scattered across some northern and southern points, these areas also present relatively favorable conditions but may face limitations such as closer proximity to roads or water resources.

3. Relatively Suitable – Indicated in yellow: Appearing as bands in the northern parts of the city, these areas may be near protected zones or dispersed settlements.

4. Moderate – Shown in orange: Found in limited extent, primarily in the northern and northeastern parts. These zones may be constrained by spatial factors such as access, soil condition, or vegetation cover.

5. Relatively Unsuitable – Represented in red: Found only in very limited zones, particularly the northernmost parts of the city. These areas are likely near residential or religious centers, sensitive water resources, or lands unsuitable for construction.

Discussion and Conclusion

The results of the fuzzy analysis within the GIS environment indicate that the eastern, southern, and western peripheral areas of Yazd city offer the highest suitability for the establishment of construction sites. These zones fall under the “Suitable” and “Highly Suitable” categories, primarily due to their adequate distance from sensitive land uses—such as residential, educational, and medical areas—and their favorable access to transportation networks and industrial centers. A comparison of these findings with previous studies reveals a consistent emphasis on the importance of proximity to transportation routes and avoidance of interference with sensitive land uses. This aligns with the results of Jafari et al. (2023) in Tehran and Yousefi & Ahmadi (2022) in Mashhad. In the present study as well, the distance from industrial centers—which had the highest weight (0.24)—proved to be a decisive factor in site selection. This finding echoes the conclusions drawn by Kumar et al. (2021), who also emphasized industrial accessibility in workshop location decisions. On the other hand, environmental criteria, such as distance from water sources and natural areas, although assigned lower weights, remain crucial for ensuring urban sustainability—a concern similarly addressed by Taheri & Razavi (2020), who stressed the need to incorporate ecological dimensions into infrastructure planning. Overall, the integrated AHP-fuzzy model within GIS successfully identified locations that balance operational, social, and environmental considerations. This approach provides a practical framework for construction site selection, particularly in historically and environmentally sensitive cities like Yazd. Based on the final fuzzy output map (Figure11), five levels of spatial suitability for construction sites establishment were identified: The "Highly Suitable" category, marked in dark green, encompasses a significant portion of the city and is mainly located along the southern, eastern, and southwestern peripheries. These areas benefit from excellent access to main roads and industrial zones, while maintaining adequate distance from residential, medical, and educational land uses. The "Suitable" areas, shown in light green, are distributed adjacent to the highly suitable zones. These include sites with generally favorable conditions but some minor constraints. "Relatively Suitable" and "Moderate" areas, shown in yellow and orange, respectively, are located closer to the urban core, where human activity density is higher. These zones often face limitations such as proximity to sensitive land uses or less direct access to industrial areas. Finally, "Relatively Unsuitable" areas, indicated in red, face the most significant constraints for workshop establishment. These zones are typically located near densely populated residential, medical, or educational areas, or lack the necessary transportation infrastructure. Their total area is limited and represents a small share of the city's overall surface. In conclusion, Figures 11 and 12 demonstrate that by applying fuzzy analysis and appropriately combining informational layers, optimal zones for the establishment of construction workshops can be accurately identified. The majority of Yazd city has been classified as "Highly Suitable" or "Suitable," indicating a strong potential for the expansion of construction activities in these areas. In contrast, only limited sections, due to unfavorable conditions, fall into the "Moderate" to "Relatively Unsuitable" categories. These findings can support urban planning decisions and the spatial allocation of civil development projects. The **Fuzzy Gamma (0.5)** function in this study provided more balanced results and was able to identify broader areas as suitable options for site selection. In contrast, **Fuzzy OR** acted more restrictively and precisely, selecting only those areas that scored highly across all criteria as suitable. Overall, the use of the Gamma function is recommended, especially for projects requiring analytical flexibility, as it allows for accurate integration of multiple criteria and delivers more acceptable results in the final suitability zoning.

Author Contributions

All authors contributed equally to the conceptualization of the article and writing of the original and subsequent drafts.

Data Availability Statement

Data available on request from the authors.

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Ethical considerations

The authors avoided data fabrication, falsification, plagiarism, and misconduct.

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Conflict of interest

The authors declare no conflict of interest.

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