Article history:
Received 05 January 2026
Revised 12 March 2026
Accepted 17 March 2026
Initial Publish 25 May 2026
Published online 01 July 2026

Journal of Resource Management and Decision Engineering

Volume 5, Issue 4, pp 1-14

Explanation and Prioritization of Factors Influencing the Location of Resilient Schools Against Natural Hazards with an Emphasis on Collective Intelligence (Case Study: Nowshahr City)

Mehdi. Elkaei Behjati[1], Seyed Ali. Seydian[2*], Mehdi. MirzaGoltabar Roshan[3]

[1] PhD Student in Architecture, Sar.C. , Islamic Azad University, Sari, Iran
[2] Associate Professor, Department of Architecture, Faculty of Arts and Architecture, University of Mazandaran, Babolsar, Iran
[3] Assistant Professor, Department of Civil Engineering, Sar.C. , Islamic Azad University, Sari, Iran

*** Corresponding author email address**: a_seyedian@umz.ac.ir

A r t i c l e I n f o

Article type:
Original Research

How to cite this article:
Elkaei Behjati, M., Seydian, S. A., & MirzaGoltabar Roshan, M. (2026). Explanation and Prioritization of Factors Influencing the Location of Resilient Schools Against Natural Hazards with an Emphasis on Collective Intelligence (Case Study: Nowshahr City). *Journal of Resource Management and Decision Engineering*, *5*(4), 1-14.
https://doi.org/10.61838/kman.jrmde.283

A B S T R A C T

This study was conducted with the aim of identifying and prioritizing the factors influencing the location of resilient schools in the face of natural hazards. The research adopted a mixed-methods approach, and data were analyzed using the Analytic Network Process (ANP), Delphi method, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Geographic Information System (GIS). The findings indicated that out of 22 initial items, 14 items were identified as key factors agreed upon by experts, encompassing physical, environmental, safety, accessibility, and socio-managerial dimensions. The results of spatial analysis, combined with collective intelligence algorithms, enabled the identification of safe and high-risk zones, as well as the optimization of evacuation routes and school site allocation. This framework can serve as a practical tool for urban planners, educational administrators, and designers of educational spaces to enhance the resilience and safety of schools.

Keywords: *resilient school site selection, natural hazards, multi-criteria analysis, GIS*

1. Introduction

The increasing frequency and intensity of natural hazards in recent decades have posed significant challenges to urban systems and public infrastructure, particularly educational facilities. Schools, as critical components of urban social infrastructure, play a dual role not only in providing education but also in functioning as emergency shelters and community support centers during crises. Consequently, ensuring the resilience of school environments against natural hazards has become a priority in urban planning and educational policy-making. International organizations such as the World Bank and UNESCO have emphasized the necessity of integrating disaster risk reduction strategies into school planning and design, highlighting that resilient schools contribute to broader community resilience and sustainable development (UNESCO, 2023; World Bank, 2024).

The concept of resilient schools encompasses multiple dimensions, including structural safety, environmental compatibility, accessibility, and socio-managerial preparedness. From a spatial planning perspective, the location of schools is one of the most critical determinants of their resilience, as inappropriate site selection can significantly increase vulnerability to hazards such as floods, earthquakes, landslides, and other environmental risks. Recent studies have shown that integrating spatial analysis with multi-criteria decision-making techniques can significantly enhance the effectiveness of school site selection by accounting for complex and interrelated factors (Elkaei Behjati et al., 2025; Sakti et al., 2022). In this regard, Geographic Information Systems (GIS) have been widely utilized as powerful tools for analyzing spatial data and supporting decision-making processes in urban resilience planning (Ardebili Pour et al., 2024; Dehghan et al., 2019).

The literature also indicates that traditional approaches to school location planning often rely on limited criteria or linear evaluation methods, which fail to capture the multidimensional and dynamic nature of urban environments. In contrast, contemporary research emphasizes the need for integrated frameworks that combine technical, environmental, social, and managerial factors to achieve optimal outcomes. For example, studies on sustainable and green school design highlight the importance of considering environmental conditions, energy efficiency, and spatial organization alongside safety and accessibility requirements (Golbargi, 2019; Xia et al., 2025). Similarly, research on school architecture underscores the role of design quality, spatial flexibility, and user-centered considerations in enhancing both safety and educational effectiveness (Hesari et al., 2020; Salimi et al., 2019).

In addition to physical and environmental factors, socio-organizational dimensions play a crucial role in shaping school resilience. The capacity of school management systems, leadership effectiveness, and organizational preparedness are essential for responding to crises and ensuring continuity of educational activities. Studies have demonstrated that strengthening leadership capacities and fostering collaborative decision-making can significantly improve the resilience of educational institutions (Larni et al., 2023; Piala et al., 2024). Furthermore, integrating educational spaces with local cultural and community contexts can enhance social cohesion and collective responsiveness during emergencies (Ran, 2024).

A critical limitation in many existing studies is the insufficient incorporation of expert knowledge and collective intelligence in the decision-making process. Given the complexity of school location planning, which involves multiple stakeholders and diverse criteria, relying solely on quantitative models may lead to suboptimal outcomes. Collective intelligence, defined as the aggregation of knowledge, experience, and judgments from multiple experts, provides a robust framework for addressing this challenge. By incorporating expert perspectives through structured methods such as the Delphi technique, decision-makers can achieve higher levels of consensus and reduce individual biases (Bahmanpour, 2023; Yaghoubi, 2025).

The integration of collective intelligence with advanced multi-criteria decision-making methods, such as the Analytic Network Process (ANP) and TOPSIS, offers a comprehensive approach to addressing the complexities of school site selection. The ANP method, unlike hierarchical models, allows for the consideration of interdependencies and feedback relationships among criteria, making it particularly suitable for complex urban planning problems. TOPSIS, on the other hand, provides a systematic mechanism for ranking alternatives based on their relative closeness to ideal solutions. When combined with GIS, these methods enable the spatial visualization of results and facilitate more informed and context-sensitive decision-making (Elkaei Behjati et al., 2025; Sakti et al., 2022).

Moreover, the application of intelligent and data-driven approaches in urban planning has gained increasing attention in recent years. The use of machine learning techniques and optimization algorithms has shown significant potential in enhancing the accuracy and efficiency of spatial decision-making processes, particularly in hazard-prone areas (Ardebili Pour et al., 2024). These approaches can complement traditional decision-making models by providing dynamic and adaptive solutions that respond to changing environmental conditions.

Another important aspect of resilient school planning is inclusivity and adaptability. Modern educational environments must accommodate diverse user needs, including those of students with disabilities, while also being flexible enough to function under emergency conditions. Research on inclusive school design emphasizes the importance of accessibility, safety, and user-centered design principles in creating resilient educational spaces (Klochko & Topaeva, 2021). Additionally, talent management and human resource development within schools contribute to organizational resilience by enhancing the capabilities of staff to respond effectively to crises (Azizi et al., 2020).

Despite the growing body of research on school resilience and site selection, there remains a gap in developing integrated frameworks that simultaneously incorporate collective intelligence, multi-criteria decision-making, and spatial analysis. Many studies focus on either technical or social dimensions in isolation, without adequately addressing the interactions among them. This limitation highlights the need for a holistic approach that combines expert knowledge, quantitative analysis, and spatial modeling to support robust decision-making processes.

In the context of cities such as Nowshahr, which are characterized by complex geographical conditions and exposure to multiple natural hazards, the importance of such integrated approaches becomes even more pronounced. Coastal–mountainous topographies, combined with urban expansion and environmental pressures, create unique challenges for the location of educational facilities. Addressing these challenges requires not only advanced analytical tools but also the effective integration of expert knowledge and stakeholder perspectives.

Accordingly, this study seeks to contribute to the existing literature by developing an integrated framework for the location of resilient schools that combines collective intelligence, multi-criteria decision-making methods, and GIS-based spatial analysis, with the aim of identifying and prioritizing the key factors influencing resilient school site selection in Nowshahr City.

2. Methods and Materials

The present study is classified as applied research in terms of its objective and as descriptive–analytical in nature, conducted using a mixed-methods approach based on multi-criteria decision-making and spatial analysis. The research framework is grounded in leveraging collective intelligence from experts and integrating the Analytic Network Process (ANP), Delphi method, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Geographic Information System (GIS) to determine optimal locations for resilient schools against natural hazards. The study area is Nowshahr City, and the analyses were carried out with the aim of reducing the vulnerability of educational spaces to environmental hazards. In the first stage, the criteria and sub-criteria influencing the location of resilient schools were identified through a systematic review of the literature and specialized documents related to school safety and natural hazard management. The extracted criteria were organized into major clusters, including natural hazards, accessibility and emergency evacuation, physical–architectural characteristics, land-use adjacency, and socio-managerial components. Subsequently, the decision network structure was developed by considering internal relationships and feedback interactions among the criteria.

To determine the weights and relative importance of the criteria, the Analytic Network Process (ANP) was employed. At this stage, pairwise comparison questionnaires were designed based on a 9-point Saaty scale and completed by a group of experts in urban planning, architecture, and crisis management. Expert judgments were aggregated using the geometric mean, and the final weights of the criteria were calculated by considering interdependencies among them. Additionally, the inconsistency ratio of the pairwise comparison matrices was examined to ensure the validity of the results.

To enhance decision-making accuracy and achieve expert consensus, the Delphi method was utilized as a complementary tool. In this stage, the criteria and weights obtained from ANP were evaluated and refined through several rounds, and those achieving an acceptable level of consensus were incorporated as final criteria in the decision-making model. This process played a significant role in operationalizing collective intelligence and reducing individual biases.

In the next stage, the TOPSIS technique was used to prioritize the proposed location alternatives. After constructing the decision matrix, normalizing the data, and applying the final weights of the criteria, the distance of each alternative from the positive and negative ideal solutions was calculated, and the alternatives were ranked based on their effectiveness in reducing vulnerability.

In the final stage, the results obtained from TOPSIS were integrated into the Geographic Information System (GIS) environment. Spatial layers related to natural hazard zones, transportation networks, land use, and other spatial data were processed, and priority maps for the optimal placement of resilient schools were generated. This integration enabled more accurate spatial analysis and alignment of multi-criteria decision-making results with the real conditions of Nowshahr City.

3. Findings and Results

In this study, to analyze the relationships and determine the relative importance of factors influencing the location of resilient schools against natural hazards, data obtained from pairwise comparison questionnaires completed by 35 experts in urban planning, architecture, and crisis management were analyzed. Descriptive statistics of pairwise comparisons among the components and sub-components of the study are presented in the figure below. Subsequently, the key findings derived from the Analytic Network Process (ANP) are interpreted.

Given the multidimensional nature of the problem and the presence of interdependencies among factors influencing school location, the Analytic Network Process (ANP) was employed as the primary analytical tool. This method enables consideration of internal interactions and feedback among criteria and offers greater capability than hierarchical approaches in analyzing complex and multi-hazard issues. The ANP network structure in this study was developed based on expert pairwise comparison questionnaires and a review of specialized literature.

Accordingly, the criteria influencing the location of resilient schools against natural hazards were organized into four main clusters, each representing a key dimension of reducing the vulnerability of educational spaces:

The natural hazards cluster includes sub-criteria such as land slope, soil type and stability, proximity to flood-prone zones and active faults, and the level of natural hazard risk.

The accessibility and emergency evacuation cluster includes indicators such as access to main road networks, emergency evacuation routes, distance to relief and fire stations, and ease of access for emergency vehicles.

The physical and architectural characteristics cluster includes land parcel size and shape, type of structural system and building resistance, density and type of adjacent land uses, and the quality of open spaces and school site safety.

The socio-managerial components cluster includes student population density, environmental security level, distance from service and educational centers, and the school's crisis management capacity.

These clusters and their associated sub-criteria formed the basis for designing the ANP decision network, and the internal relationships and interdependencies among them were incorporated into the design of the pairwise comparison questionnaires.

The results of pairwise comparisons indicated that within the natural hazards cluster, sub-criteria related to earthquakes and floods exhibited moderate to relatively high interdependency. In particular, the effect of flood-prone zones on land subsidence, with a mean value of 5.94, emphasizes the necessity of integrated and simultaneous evaluation of natural hazards in the school location process. In the accessibility and emergency evacuation cluster, the strongest relationship was observed between pedestrian pathway width and access to fire stations, with a mean value of 6.54, indicating the importance of simultaneously designing transportation routes and appropriately locating emergency facilities to reduce response time in crisis situations. In contrast, some indicators, such as evacuation time and distance to fire stations, showed weaker interdependency and functioned relatively independently.

Within the physical and architectural characteristics cluster, criteria such as reducing structural dead load, geometric regularity of the plan, and the presence of safe open spaces (e.g., central courtyards) had relatively similar and significant impacts on enhancing school resilience. These results highlight the importance of simultaneously considering structural and spatial aspects in school design and location. Finally, within the socio-managerial components cluster, relationships among indicators such as population density and adjacency to public open spaces had a lower mean value (approximately 4.31), indicating that these criteria play a complementary and desirability-based role and gain significance alongside technical and safety criteria. Overall, the ANP analysis demonstrated that criteria related to natural hazards and emergency accessibility play the most significant role in reducing vulnerability and enhancing school resilience, while physical–architectural and socio-managerial criteria serve supportive and complementary functions. These findings indicate that the location of resilient schools requires an integrated approach in which environmental safety considerations, emergency accessibility, and physical and social capacities are simultaneously addressed.

To evaluate the reliability of the pairwise comparison questionnaire, Cronbach's alpha coefficient was calculated, yielding a value of 0.66. This value indicates relatively acceptable reliability and moderate internal consistency among the items, which is considered acceptable given the exploratory nature of the study, the specialized subject matter, and the limited expert population. The results suggest that the questionnaire items possess sufficient internal coherence for subsequent analyses. Additionally, to assess sampling adequacy and the feasibility of factor analysis, the Kaiser–Meyer–Olkin (KMO) index and Bartlett's test of sphericity were calculated. The KMO value was 0.64, indicating acceptable data adequacy for factor analysis. Bartlett's test results were significant, confirming the presence of sufficient correlations among variables and the suitability for factor extraction. For ease of coding and statistical analysis, questionnaire items were labeled from q01 to q22.

Pairwise comparison questionnaires were designed separately for the sub-criteria of each cluster and completed by experts. The collected responses were aggregated using the geometric mean, and the final weight of each criterion was calculated by considering interdependencies within the ANP framework. Furthermore, the inconsistency ratio of the pairwise comparison matrices was examined and found to be within an acceptable range, indicating the validity of expert judgments and the accuracy of the results. To examine the factor structure and construct validity, Exploratory Factor Analysis (EFA) was conducted. The results showed that the factor loadings of all items were within acceptable ranges, and two main factors with satisfactory explained variance were extracted. These findings confirm the conceptual coherence of the constructs and the logical correlation among the questionnaire items (Field Findings, 2025).

Subsequently, Confirmatory Factor Analysis (CFA) was employed to evaluate the fit of the measurement model. Examination of standardized factor loadings indicated that some items, including q4 and q7, had loadings below 0.50 and played a weaker role in explaining their respective factors. Given the exploratory nature of the study, these items were identified as candidates for revision and may be modified or removed in future studies to improve model fit. To illustrate the CFA results, the model path diagram is presented in the figure below, showing the relationships among factors, items, and standardized factor loadings.

Figure 1

Confirmatory Factor Analysis (CFA) – Measurement Model Validation

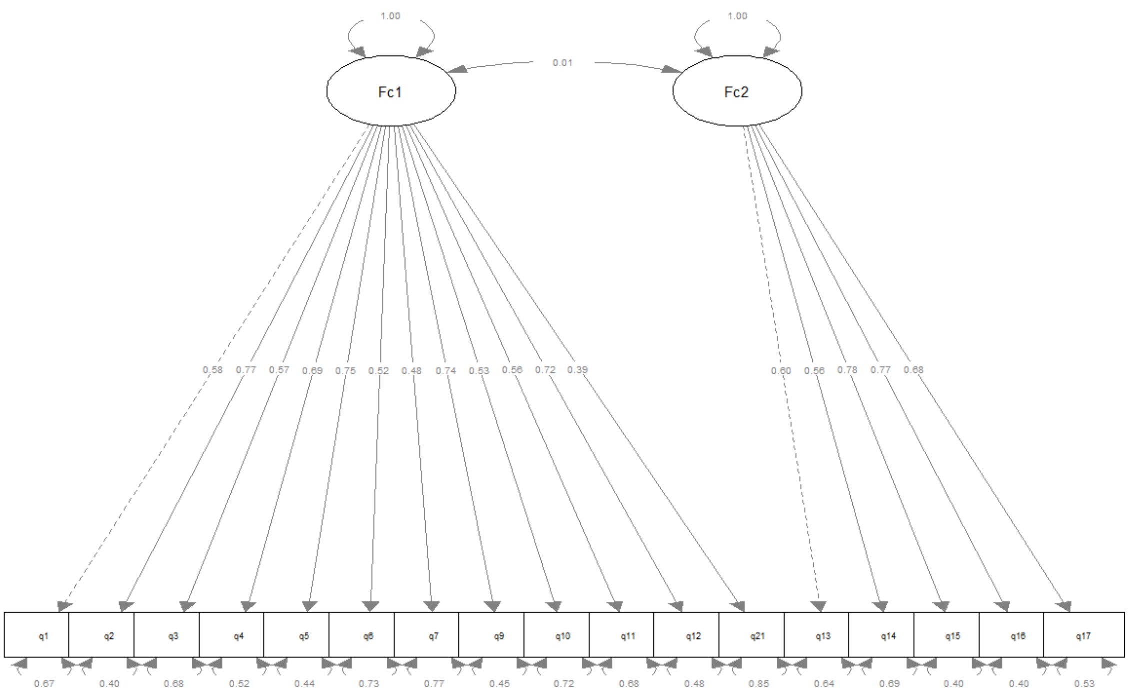


Table 1

Pearson Correlation Test Results

Variables	r	t	df	p-value	CI_low	CI_high
Factor1 ↔ Factor2	0.166	0.97	33	0.341	-0.177	0.473

The results obtained from applying the multi-criteria decision-making model TOPSIS conceptually clarified the prioritization of location alternatives for schools. Some blocks clearly exhibited optimal conditions for resilience against natural hazards and possessed the necessary capacities to reduce vulnerability and facilitate evacuation processes and emergency access. These blocks can be considered as proposed locations for the construction or reconstruction of schools. In contrast, some areas were characterized by spatial constraints, lower accessibility, or unfavorable environmental conditions, indicating the necessity for physical improvements or the selection of better alternatives. The TOPSIS analysis enabled the study not only to perform a numerical ranking but also to explain the real implications of urban decision-making and its effects on school resilience and safety. Overall, the integration of Delphi and TOPSIS results demonstrated that the location of resilient schools is a multidimensional process that must simultaneously consider technical, physical, social, and environmental criteria. Expert consensus and multi-criteria analysis contributed to identifying the most influential factors and evaluating location alternatives based on practical and safety priorities. This analytical approach facilitates more informed decision-making and reduces the vulnerability of educational spaces in the face of natural hazards.

Table 2

TOPSIS Model Output

Block	Block (Label)	Score	Rank
A	Block A	0.7336	1
D	Block D	0.7220	2
C	Block C	0.3229	3
B	Block B	0.2032	4

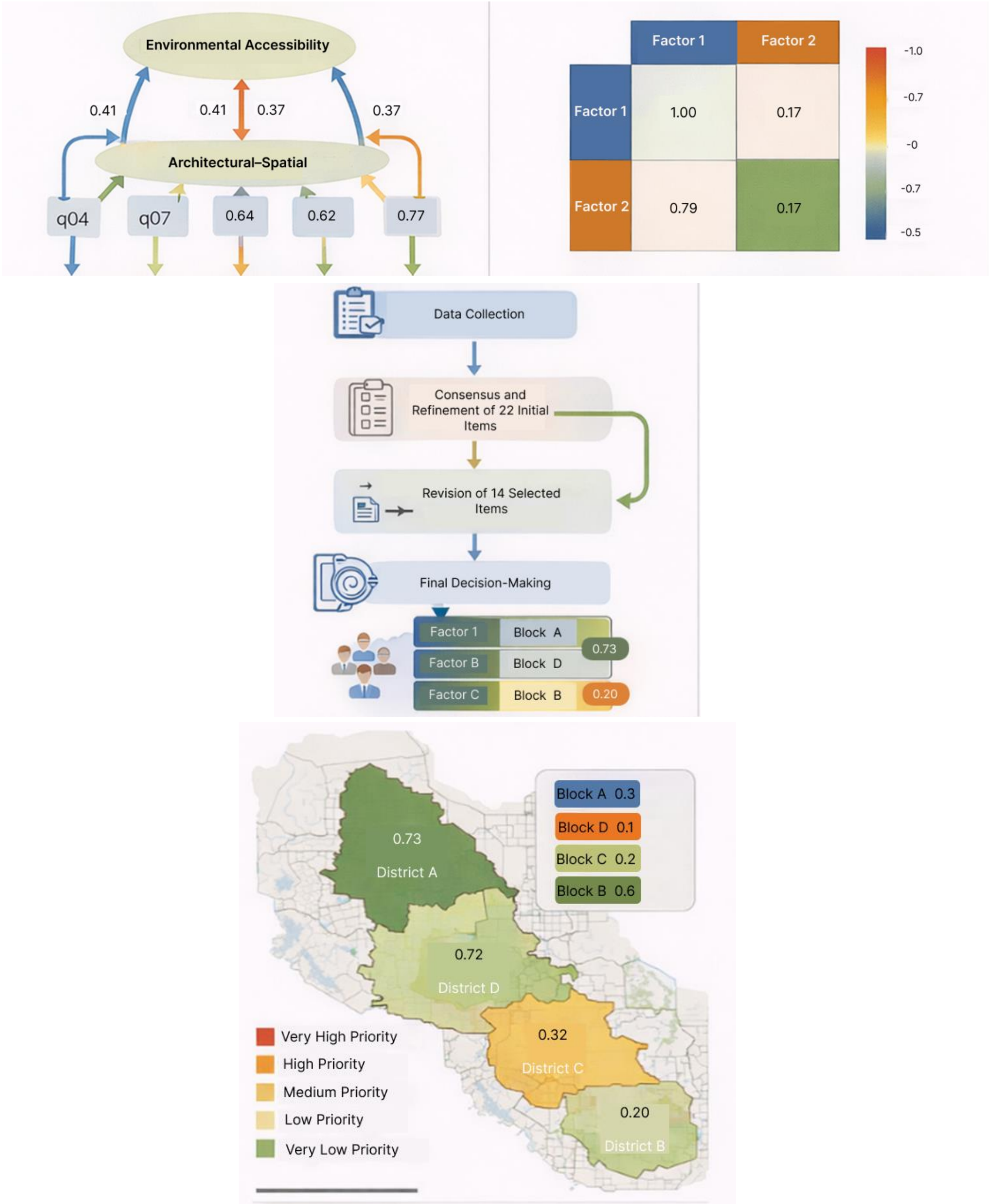
Table 3

Ranking of Block A

Question	Mean	SD	Importance	Consensus	Topsis_Score	Rank
Q10	8.60	0.69	5	5	1.000000	1
Q08	8.54	0.70	5	5	0.992914	2
Q09	8.51	0.70	5	5	0.990236	3
Q02	8.17	0.79	5	5	0.943779	4
Q03	8.14	0.81	5	5	0.936791	5

Figure 2

Integrated Analysis and Prioritization of Key Components for Locating Resilient Schools Against Natural Hazards in Nowshahr City Using Expert Judgment, Collective Intelligence, and Multi-Criteria Decision-Making Methods



To achieve the final prioritization of factors identified in the Delphi stage, the TOPSIS technique was employed. In this regard, the outputs of the Delphi model, including mean scores, level of importance, and level of consensus, were considered as input criteria for the model. The weights of the criteria were set as 0.3 for the mean, 0.2 for the standard deviation, 0.3 for the importance level, and 0.2 for the consensus level. The results of the TOPSIS model indicated a distribution of final scores between 0 and 1, where options with scores closer to 1 had higher priority and importance. Accordingly, questions Q10, Q08, and Q09 were identified as the primary priorities.

Spatial decision-making in the context of school location, due to the interwoven nature of physical, social, environmental, and urban safety factors, requires a multi-criteria approach grounded in expert perspectives in architecture and urban planning. In this study, collective intelligence was employed as the primary decision-making framework to integrate the individual judgments of architects, urban planners, and crisis management experts into a consensual and reliable body of knowledge. In the first stage, the ANP model was applied with the participation of 35 specialists in urban design and architecture to determine the weights of criteria and their interrelationships. The final weights were derived using the geometric mean aggregation of expert judgments, reflecting the realization of collective wisdom in spatial design and analysis.

Subsequently, the Delphi method was used to achieve final expert consensus, and from the initial 22 items, 14 items were selected based on both spatial importance and expert agreement. These items included physical, accessibility, safety, and socio-spatial management components, forming the core of the resilient school location framework. Then, the Delphi outputs were used as inputs for the TOPSIS model to rank school location alternatives based on weights derived from collective intelligence and architectural and urban criteria. The results showed that Blocks A, D, and C had the highest levels of spatial and functional desirability, respectively.

In the final stage, the TOPSIS results were integrated into the GIS environment and represented as thematic and spatial maps, illustrating the concentration pattern of priority schools in central and safe areas of the city. Overall, the findings indicate that integrating collective intelligence with multi-criteria decision-making models and GIS-based spatial analysis provides an efficient and reliable framework for planning and designing resilient school infrastructure in urban areas. This approach can assist architects, urban planners, and educational administrators in optimizing school location and enhancing urban resilience.

Table 4

School Location Based on Collective Intelligence

Stage	Analytical Tool	Representation of Collective Intelligence
Data Collection	ANP Questionnaire	Aggregation of judgments from 35 experts in pairwise comparison matrices
Consensus and Refinement	Delphi Model	Convergence and reduction of opinion dispersion through group feedback
Final Decision-Making	TOPSIS Model	Transformation of collective intelligence into numerical decision-making and spatial ranking
Spatial Analysis	GIS Model	Representation of collective decisions in the form of spatial and thematic maps

Overall, the approach adopted in this study represents a practical example of utilizing collective intelligence in the spatial design and management of schools and in reducing environmental vulnerability. The integration of ANP, Delphi, and TOPSIS methods within a GIS environment demonstrated that location decision-making based on collective expert evaluation and multidimensional criteria enhances accuracy, comprehensiveness, and spatial efficiency in the process of locating resilient schools. For spatial analysis of the TOPSIS results, the ranked data were integrated with spatial layers, and thematic maps were generated. This integration enabled the spatial representation of scores and the prioritization of regions based on natural hazards and emergency indicators. The results indicated that Nowshahr County, due to its coastal–mountainous conditions and exposure to multiple urban and natural hazards, requires an integrated approach in the design and location of schools. Furthermore, the application of collective intelligence algorithms such as Ant Colony Optimization (ACO) and Artificial Bee Colony (ABC), by transforming the analysis from a static state into spatial and functional dynamics, significantly increased the accuracy and efficiency of location decision-making and school spatial arrangement, enabling the optimization of access and emergency evacuation routes as well as the appropriate distribution of educational spaces within the urban fabric.

Table 5

Integration of TOPSIS Output Data with the GIS Model

RegionID	Name	Population	Area (km²)	Question	Topsis_Score	Rank	Priority_Level	Weighted_Score
1	Region 1	412312	4443.698398	Q10	0.92	1	Very High Priority	3.7932704
2	Region 2	40537	957.7579863	Q08	0.89	2	Very High Priority	0.3607793
3	Region 3	459434	740.408887	Q09	0.87	3	Very High Priority	3.9970758
4	Region 4	235588	3300.199433	Q02	0.78	4	High Priority	1.8375864
5	Region 5	411204	1783.230714	Q01	0.76	5	High Priority	3.1251504
6	Region 6	154607	3318.114827	Q03	0.75	6	High Priority	1.1595525
7	Region 7	387048	1669.828688	Q14	0.72	7	High Priority	2.7867456
8	Region 8	100076	1019.686484	Q13	0.68	8	High Priority	0.6805168
9	Region 9	278359	3933.242076	Q04	0.67	9	High Priority	1.865053
10	Region 10	224590	558.6154349	Q11	0.65	10	High Priority	1.459835
11	Region 11	301537	2387.217304	Q12	0.62	11	High Priority	1.8695294
12	Region 12	63240	2060.376754	Q06	0.58	12	Moderate Priority	0.366792
13	Region 13	169896	3039.9459	Q05	0.56	13	Moderate Priority	0.9514176
14	Region 14	378916	1730.835348	Q07	0.55	14	Moderate Priority	2.084038
15	Region 15	403256	2494.203865	Q22	0.32	15	Low Priority	1.2904192
16	Region 16	417641	4776.921755	Q21	0.28	16	Low Priority	1.1693948
17	Region 17	246766	2466.221746	Q20	0.25	17	Low Priority	0.616915
18	Region 18	476035	4462.716088	Q16	0.23	18	Low Priority	1.0948805
19	Region 19	381461	4580.747116	Q17	0.20	19	Low Priority	0.762922
20	Region 20	192727	3082.801413	Q15	0.19	20	Very Low Priority	0.3661813
21	Region 21	366181	2112.379905	Q19	0.17	21	Very Low Priority	0.6225077
22	Region 22	461742	820.7639856	Q18	0.15	22	Very Low Priority	0.692613

Figure 3

Geographic Information System of Nowshahr County

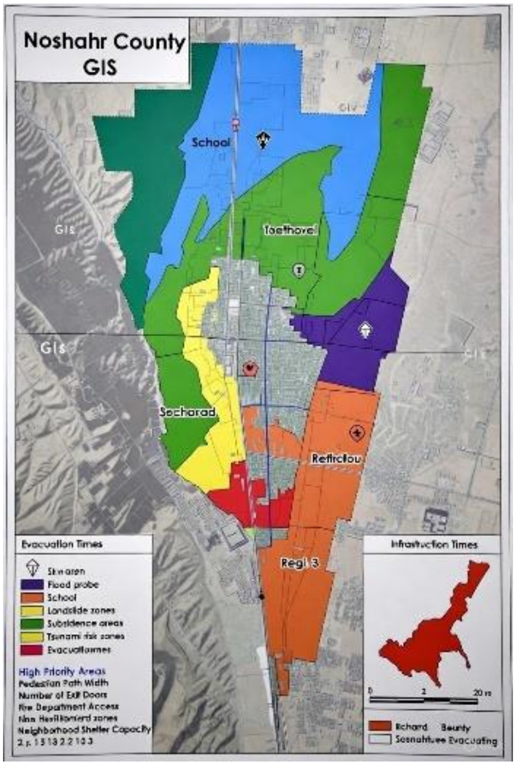
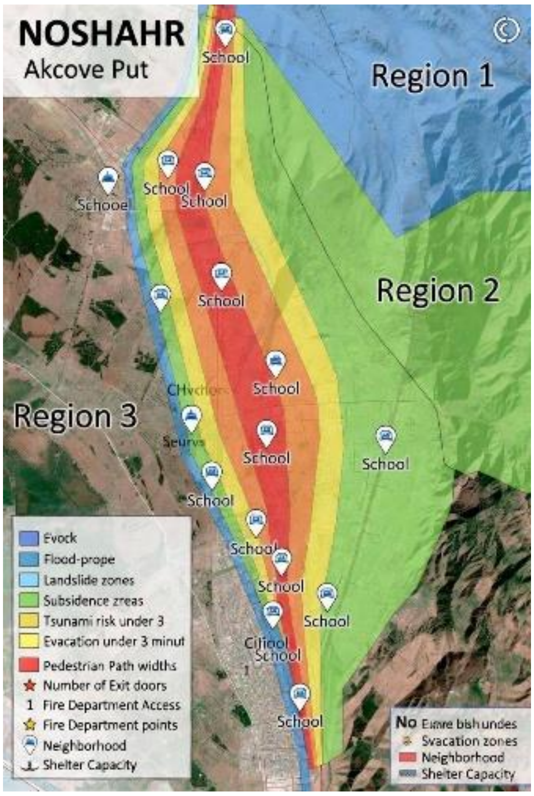


Figure 4

Integration of the Nowshahr GIS with the Model



Data analysis indicates that a limited but critical set of factors exerts the greatest influence on the location of resilient schools against natural hazards. The implementation of the Delphi method with the participation of 35 experts and multiple evaluation rounds led to the identification of 14 key factors that were confirmed both in terms of importance and expert consensus. This refinement of indicators enabled a focus on influential elements and reduced the complexity of the decision-making process, while other less influential or conceptually ambiguous factors were removed from the model.

The results of integrating multi-criteria decision-making (TOPSIS) with GIS-based spatial analysis provide a precise perspective on the spatial distribution of priorities. Areas that exhibit suitable conditions in terms of safety indicators, accessibility, shelter capacity, and population characteristics were identified as optimal options for school placement. In contrast, areas adjacent to high-risk coastal zones, steep slopes, or regions prone to landslides and flooding require additional safety assessments, resilient structural design, and emergency planning.

The use of collective intelligence algorithms such as ACO and ABC enabled the optimization of evacuation routes and the selection of low-risk sites with high population coverage. Spatial analysis demonstrated that by applying a combination of these tools, safe zones can be identified and high-risk areas can be clearly distinguished in spatial planning. This approach is particularly effective in urban environments with complex topography, enhancing emergency accessibility management and the design of resilient schools.

4. Discussion and Conclusion

The findings of this study provide a comprehensive and multidimensional understanding of the factors influencing the location of resilient schools in the context of natural hazards, demonstrating the effectiveness of integrating collective intelligence with multi-criteria decision-making models and spatial analysis. The results indicated that among the identified clusters, criteria related to natural hazards and emergency accessibility had the greatest influence on reducing vulnerability and enhancing resilience. Specifically, sub-criteria such as proximity to flood-prone areas, active fault zones, and soil stability emerged as critical determinants, highlighting the necessity of prioritizing environmental risk factors in school site selection. These findings are consistent with prior studies emphasizing that hazard-sensitive spatial planning significantly contributes to reducing disaster risks in educational environments (Sakti et al., 2022; World Bank, 2024).

Furthermore, the strong interdependencies observed within the natural hazards cluster, particularly between flood-prone areas and land subsidence, underscore the importance of adopting an integrated approach to hazard assessment. Rather than evaluating risks in isolation, the results suggest that simultaneous consideration of multiple hazards is essential for accurate decision-making. This aligns with research indicating that multi-hazard assessment frameworks enhance the robustness of spatial planning and improve resilience outcomes in urban systems (Ardebili Pour et al., 2024; Dehghan et al., 2019). The application of ANP in this study allowed for the modeling of such interdependencies, providing a more realistic representation of the complex relationships among criteria compared to traditional hierarchical approaches.

In addition to environmental factors, the findings highlighted the critical role of accessibility and emergency evacuation infrastructure in determining school resilience. The strong relationship between pedestrian pathway width and access to emergency services, such as fire stations, indicates that efficient transportation networks are essential for minimizing response times during crises. This result corroborates previous research emphasizing the importance of accessibility and connectivity in enhancing the effectiveness of emergency response systems and ensuring the safety of school populations (Ajuwon et al., 2024; Bahmanpour, 2023). The prioritization of these factors in the TOPSIS analysis further reinforces their significance in practical decision-making contexts.

The analysis also revealed that physical and architectural characteristics, while slightly less influential than hazard and accessibility factors, play a substantial supporting role in enhancing school resilience. Criteria such as structural stability, geometric regularity, and the availability of safe open spaces were identified as important contributors to overall resilience. These findings are consistent with studies on school architecture and design, which highlight the importance of integrating safety considerations with functional and spatial design principles (Hesari et al., 2020; Salimi et al., 2019). Moreover, the emphasis on open spaces as safe zones for evacuation aligns with international guidelines for school safety and disaster preparedness (UNESCO, 2023).

Another significant finding of this study is the relatively lower influence of socio-managerial factors compared to technical and environmental criteria. While variables such as population density and proximity to service centers were found to have a complementary role, their impact on resilience was less direct. This does not diminish their importance but rather indicates that their effectiveness is contingent upon the presence of adequate physical and environmental conditions. This observation is supported by research suggesting that organizational resilience and management capacity enhance the effectiveness of structural and environmental interventions rather than acting as standalone determinants (Larni et al., 2023; Piala et al., 2024).

The integration of the Delphi method in this study played a crucial role in refining the criteria and achieving expert consensus. The identification of 14 key factors from an initial set of 22 demonstrates the effectiveness of collective intelligence in simplifying complex decision-making processes while retaining essential information. This finding is consistent with previous studies highlighting the value of expert consensus in improving the reliability and validity of multi-criteria decision-making models (Bahmanpour, 2023; Yaghoubi, 2025). By reducing ambiguity and focusing on the most relevant factors, the Delphi method enhanced the overall efficiency and applicability of the model.

The results of the TOPSIS analysis provided a clear prioritization of spatial alternatives, with certain blocks demonstrating significantly higher suitability for resilient school location. The identification of high-priority zones reflects the successful integration of multiple criteria, including hazard exposure, accessibility, and spatial characteristics. This outcome aligns with prior research indicating that multi-criteria ranking methods are effective tools for evaluating and comparing spatial alternatives in complex urban environments (Elkaei Behjati et al., 2025; Sakti et al., 2022). The ability of TOPSIS to incorporate both quantitative and qualitative data further enhances its applicability in real-world planning scenarios.

The integration of TOPSIS results with GIS-based spatial analysis provided valuable insights into the geographical distribution of suitable locations. The spatial visualization of priorities enabled the identification of safe zones and high-risk areas, facilitating more informed and context-sensitive decision-making. This finding is in line with studies emphasizing the role of GIS as a critical tool for spatial decision support in urban planning and disaster risk management (Ardebili Pour et al., 2024; Dehghan et al., 2019). The combination of spatial and analytical methods thus represents a significant advancement in the field of school location planning.

An important contribution of this study is the incorporation of collective intelligence algorithms, such as ACO and ABC, to enhance the dynamic aspects of spatial decision-making. The application of these algorithms enabled the optimization of evacuation routes and the identification of low-risk areas with high population coverage, thereby improving the overall efficiency of the planning process. This approach reflects emerging trends in the use of intelligent systems and optimization techniques in urban resilience planning (Ran, 2024; Xia et al., 2025). By transitioning from static analysis to dynamic modeling, the study demonstrates the potential of advanced computational methods to address complex spatial challenges.

The findings also highlight the importance of adopting a holistic and integrated approach to school location planning. The interplay between environmental, physical, and social factors underscores the need for comprehensive frameworks that consider multiple dimensions simultaneously. This perspective is consistent with global recommendations for resilient infrastructure development, which emphasize the integration of risk assessment, design, and management strategies (UNESCO, 2023; World Bank, 2024). The proposed framework in this study provides a practical example of how such integration can be achieved in the context of educational facilities.

Moreover, the study contributes to the growing body of literature on sustainable and resilient urban development by demonstrating the applicability of multi-criteria decision-making methods in complex planning scenarios. The integration of ANP, Delphi, and TOPSIS within a GIS environment offers a robust and flexible framework that can be adapted to different contexts and scales. This approach addresses the limitations of traditional methods and provides a more comprehensive basis for decision-making in hazard-prone areas.

Despite these contributions, the findings also reveal certain challenges and areas for improvement. The relatively moderate reliability of the questionnaire indicates the inherent complexity of capturing expert judgments in multidimensional decision-making processes. Additionally, the lower factor loadings observed for some items in the CFA analysis suggest the need for further refinement of measurement instruments. These issues highlight the importance of continuous methodological development and validation in future research.

Another notable implication of the findings is the potential for integrating emerging technologies, such as machine learning and data analytics, into the decision-making framework. The increasing availability of spatial and environmental data provides opportunities for enhancing the accuracy and predictive capabilities of models used in school location planning. This aligns with recent studies advocating for the use of advanced computational tools in urban resilience and disaster risk management (Ardebili Pour et al., 2024; Xia et al., 2025).

In conclusion, the results of this study demonstrate that the integration of collective intelligence, multi-criteria decision-making, and spatial analysis provides a comprehensive and effective approach to the location of resilient schools. By identifying key factors, prioritizing spatial alternatives, and visualizing results within a GIS environment, the study offers valuable insights for urban planners, policymakers, and educational administrators. The findings underscore the importance of adopting integrated and data-driven approaches to enhance the resilience and safety of educational environments in the face of increasing natural hazards.

One of the main limitations of this study is the reliance on expert judgment, which, despite being systematically structured through Delphi and ANP methods, may still be influenced by subjective biases and the specific expertise of the selected participants. The sample size of 35 experts, while adequate for exploratory analysis, may limit the generalizability of the findings to other contexts. Additionally, the study focuses on a specific geographical area, which may restrict the applicability of the results to regions with different environmental and socio-economic conditions. Another limitation relates to the availability and accuracy of spatial data, which can affect the precision of GIS-based analyses and the reliability of the final outcomes.

Future research can build upon the findings of this study by expanding the scope to include multiple cities with diverse geographical characteristics, thereby enhancing the generalizability of the proposed framework. Additionally, the integration of real-time data and advanced analytical techniques, such as machine learning and predictive modeling, can further improve the accuracy and adaptability of decision-making processes. Researchers may also explore the incorporation of stakeholder perspectives, including students, parents, and local communities, to complement expert judgments and provide a more comprehensive understanding of resilience in educational environments. Furthermore, longitudinal studies examining the performance of selected school locations over time can provide valuable insights into the long-term effectiveness of the proposed approach.

From a practical perspective, the findings of this study offer valuable guidance for urban planners, architects, and educational policymakers in designing and implementing resilient school infrastructure. Decision-makers can utilize the integrated framework presented in this study to systematically evaluate potential school locations and prioritize investments based on risk reduction and safety considerations. The use of GIS-based spatial analysis can facilitate the visualization of priorities and support evidence-based planning. Additionally, incorporating collective intelligence into decision-making processes can enhance the quality and acceptance of planning outcomes by ensuring that diverse expert perspectives are considered. Finally, the application of optimization algorithms for evacuation planning and spatial distribution can improve emergency preparedness and contribute to the overall resilience of urban communities.

Authors' Contributions

Authors contributed equally to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

Acknowledgments

We would like to express our gratitude to all individuals helped us to do the project.

Declaration of Interest

The authors report no conflict of interest.

Funding

According to the authors, this article has no financial support.

Ethics Considerations

In this research, ethical standards including obtaining informed consent, ensuring privacy and confidentiality were considered.

References

Ajuwon, O. A., Animashaun, E. S., & Chiekezie, N. R. (2024). Crisis Intervention, Mediation, Counseling, and Mentoring in Schools: Building Resilient Educational Communities. *International Journal of Applied Research in Social Sciences*, *6*(8), 1593-1611. https://doi.org/10.51594/ijarss.v6i8.1372

Ardebili Pour, M., Ghiasi, M. B., & Karkehabadi, A. (2024). Applying machine learning tools for urban resilience against floods.

Azizi, G., Ezzati, M., & MohammadDavvodi, A. (2020). Presenting Talent Management Model in Tehran City Schools: A Qualitative Study. *School administration*, *8*(3), 50-29. https://jsa.uok.ac.ir/article_61495.html

Bahmanpour, A. (2023). Location of temporary housing and crisis management sites (A case study). *Disaster Prevention and Management Knowledge*, *13*(1), 80-92.

Dehghan, M., Azari, M., & Sepehr, A. (2019). Presenting a GIS-based decision support system for prioritizing water and soil conservation measures (A case study). *Quarterly Journal of Environmental Spatial Planning*, *29*, 65-82.

Elkaei Behjati, M., Seyedian, S. A., & Mirzagoltabar Roshan, M. (2025). Optimal school site selection with a risk reduction approach: Integrating GIS and multi-criteria decision-making methods. *Manifestation of Art in Architecture and Urbanism*, *26*(1).

Golbargi, S. R. (2019). Ranking of School Criteria Based on the Sustainability Approach in Order to Design Green Schools. Third National Conference on New Academic Research in Art, Architecture and Civil Engineering.

Hesari, P., Mohtasham, A., & Farzanddoost, A. (2020). Strategies to Improve School Architectural Design Quality with Emphasis on Gardner's Multiple Intelligences. *Educational Technology*, *14*(2), 341-353. https://sid.ir/paper/374880/fa

Klochko, A. R., & Topaeva, P. A. (2021). Current Trends in the Architectural Design of Inclusive Schools. *Stroitel Stvo Nauka I Obrazovanie [Construction Science and Education]*, *11*(3), 23-40. https://doi.org/10.22227/2305-5502.2021.3.2

Larni, M., Belyad, M. R., Irannejad, P., & Mohammadinejad Ganji, A. (2023). Identifying dimensions and components of organizational resilience of crisis management in academic centers to deal with natural hazards. *Sociology of Education*, 1-20.

Piala, M., Kilag, O. K., Abella, J., Groenewald, E., Cordova Jr, N., & Tañiza, F. N. (2024). Building Capacity, Driving Impact: A Holistic Approach to School Leader Development. *Excellencia: International Multi-disciplinary Journal of Education*, *2*(1), 25-35. https://multijournals.org/index.php/excellencia-imje/article/view/271

Ran, Y. (2024). Excellent Case of Building a "School-Land" Co-Construction and Sharing Pattern Network of School Aesthetic Education and Regional Culture. *Jes*, *20*(2), 740-744. https://doi.org/10.52783/jes.1229

Sakti, A. D., Rahadianto, M. A. E., & Wikantika, K. (2022). School location analysis by integrating accessibility, natural and biological hazards for educational equity. *Isprs International Journal of Geo-Information*, *11*(1), 12.

Salimi, M., Jalali, M., & Yousefi Tazakor, M. (2019). Architectural Requirements of Schools With a Focus on Enhancing Students' Creativity and Abilities. *Journal of Architecture Studies*(192), 185-113. https://elmnet.ir/doc/2212033-14378

UNESCO. (2023). *Education and school safety: integrating disaster risk reduction*.

World Bank. (2024). *Building safer and more resilient schools in a changing climate*.

Xia, T., Ali, A., & Mahyuddin, N. (2025). Multi-Objective Optimization of Window Design for Energy and Thermal Comfort in School Buildings: A Sustainable Approach for Hot-Humid Climates. *Sustainability*, *17*, 8646. https://doi.org/10.3390/su17198646

Yaghoubi, M. (2025). Ranking secondary schools based on the management excellence model with an integrated approach and TOPSIS method. *Applied Studies in Educational Management and E-Learning*, *2*(1), 43-50.