Hindawi
Mathematical Problems in Engineering
Volume 2021, Article ID 5944828, 22 pages
https://doi.org/10.1155/2021/5944828

Research Article

Efficient Crisis Management by Selection and Analysis of Relief Centers in Disaster Integrating GIS and Multicriteria Decision Methods: A Case Study of Tehran

Hassan Ahmadi Choukolaei,[1] Mustafa Jahangoshai Rezaee ,[1] Peiman Ghasemi,[2] and Morteza Saberi[3]

[1]*Faculty of Industrial Engineering, Urmia University of Technology, Urmia, Iran*
[2]*Department of Industrial Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran*
[3]*School of Information, Systems and Modelling, University of Technology Sydney, Sydney, NSW, Australia*

Correspondence should be addressed to Mustafa Jahangoshai Rezaee; m.jahangoshai@uut.ac.ir

Received 28 April 2021; Revised 21 May 2021; Accepted 17 June 2021; Published 2 July 2021

Academic Editor: Mohammad Yazdi

In Iran, location is usually done by temporary relief organizations without considering the necessary standards or conditions. The inappropriate and unscientific location may have led to another catastrophe, even far greater than the initial tragedy. In this study, the proposed locations of crisis management in the region and the optimal points proposed by the Geographic Information System (GIS), taking into account the opinions of experts and without the opinion of experts, were evaluated according to 18 criteria. First, the optimal areas have been evaluated according to standard criteria extracted by GIS and the intended locations of the region for accommodation in times of crisis. Then, the position of each place is calculated concerning each criterion. The resulting matrix of optimal options was qualitatively entered into the Preference Ranking Organization Method for Evaluation (PROMETHEE) for analysis. The triangular fuzzy aggregation method for weighting and standard classification of criteria for extracting optimal areas using GIS and integrating entropy and the Multiobjective Optimization Based on Ratio Analysis (MOORA) method for prioritizing places in the region are considered in this research. Finally, by applying constraints and using net input and output flows, optimal and efficient options are identified by PROMETHEE V. Among the research options, only four options were optimal and efficient. A case study of the Tehran metropolis is provided to show the ability of the proposed approach for selecting the points in three modes, with/without applying weights and applying crisis management.

1. Introduction

Natural disasters, especially earthquakes, have long been considered the most destructive factors that harm humans, society, and habitat. Data show that natural disasters such as earthquakes have increased in recent years. Therefore, the need for proper planning for equipment before the disaster is more important than ever [1–3]. During a crisis, homes are often damaged or unsafe for use, and at this time, creating suitable temporary shelters for families is very important. Temporary shelter is transferring people from emergency shelters to their permanent housing, which is provided to homeless families for several months to several years. Transforming urban spaces into temporary shelters is an effective way to support and improve the aftermath of natural disasters [4]. The process of selecting a temporary location for use in future critical situations must be done in a principled manner. Because the main need of the injured people is to have shelter and provide relief services in the fastest possible time, it is not possible to provide suitable places for earthquake victims immediately after the earthquake. In such crises, the right places (urban access, security, avoidance of risk-prone areas, and so on) should be provided to earthquake victims [5]. Because the injured person without shelter is exposed to serious physical, mental, and psychological injuries. For this reason, selecting an appropriate and safe location is very important in urban planning. Improper location of relief centers will lead to a crisis far worse than the initial crisis. For example, not observing the distance between relief centers and fault lines will lead to the destruction of these places during aftershocks, which will injure or kill many people due to the role of relief centers in crises. Due to the active faults in the region and the importance of locating relief centers in times of crisis, in this study, relief centers considered by Tehran Crisis Management with optimal centers extracted by the Geographic Information System (GIS) in terms of efficiency, performance, and optimization have been evaluated. Also, in this study, by comparing the desired methods and locations in the area and the proposed locations of GIS, it has been tried to introduce the most optimal locations or areas for temporary accommodation of people in critical situations by evaluating potential locations and areas. Comparison and review of points considered by the Regional Crisis Management Organization and points introduced by GIS are other topics studied in this research. Many researchers have focused specifically on planning and policy-making. Researchers and crisis management managers are willing to act in decisions that can improve system performance as much as possible. Hosseini and Machyani [6] identified and ranked places prone to food storage and facilities in times of crisis. They used the GIS method and the AHP method. Esmaelian et al. [7] proposed a multicriteria spatial decision that integrates a GIS support system and a multicriteria decision method to identify evacuation shelters and emergency service locations. Marcelin et al. [8] have adopted a p-median modeling framework with GIS. Their goal was to discover the locations of relief distribution facilities after a possible storm in the city of Leon, Florida. Chen et al. [9] designed a system theory-based planning framework and GIS in China for urban emergency shelters in critical situations. In this study, the opinions of local experts and citizens were used to build temporary settlements in Guangzhou. The results showed that this framework is a good tool for planning urban emergency shelters. Saeidian et al. [10] have used (GIS), TOPSIS method, a simple clustering method, and two metaheuristic algorithms (particle swarm optimization (PSO) and ant colony optimization (ACO)) to locate relief centers. The results of the evaluations showed that PSO responds better than ACO and has higher adaptability. Nappi et al. [11] have proposed a new multicriteria decision model that focuses on humanitarian to select temporary collective shelters. The results quantify the importance of criteria and allow the development of a SHELTERPRO software decision tool that can be used for support. The results also showed that facility safety, cultural adequacy, and access to space were the most valuable criteria. Baharmand et al. [12] have developed a spatial allocation model and applied their approach to a real data set of Nepal 2015 earthquake response. The analysis showed that with a relative coverage of 0.4, the balance between procurement costs and response time affects the number and location. Borhani et al. [13] identified the shelters and multipurpose spaces by analyzing the collected data and the opinions of 26 experts using the GIS and SAW model. Su et al. [14] developed a two-stage floating catchment (2SFCA) method with variable service radius, and evacuation radius has been developed to describe emergency shelter access in the main Lanzhou area and compare it with traditional 2SFCA. Yao et al. [15] used a multicriteria TOPSIS evaluation model and, through a combined process, service area, and POI analysis, developed a model that provided an overall assessment at the district level. The results showed that the distribution of open spaces did not match the dynamics of population distribution. Considering the existing challenges in the literature of the subject as well as the analysis of studies, the research gap can be expressed as follows:

(i) Lack of attention to location constraints

(ii) Lack of attention to the efficiency of the optimal locations

(iii) Lack of attention to the feasibility of the output of the GIS

Given the research gap mentioned, the research contributions are listed as follows:

(i) Using PROMETHEE V to consider constraints to suggest optimal locations

(ii) Determining the efficiency of the final optimal options according to the net input and output currents

(iii) Determining the feasibility of the extracted places

The rest of the paper is organized as follows. In the second section, the criteria for measuring criteria and ranking options will be explained. In Section 3, the proposed approach and problem statement will be expressed. In Section 4, we will introduce a case study. In the fifth and sixth sections, the data, output analysis, and related results will be described, respectively. Finally, the conclusion will be stated in the last section.

2. Methodology

The methodology of this research consists of four parts. These methods were used to weigh the criteria and prioritize the options. Research weighting methods include the triangular fuzzy method and entropy. MOORA and PROMETHEE methods have also been used to prioritize options. The entropy-MOORA combination method was used in the second phase of the research to rank the relief sites in the area, and the PROMETHEE method was used to prioritize the options. The PROMETHEE V method has been used to determine the final optimal options and compare the performance of the methods.

2.1. Weighting Method. The use of fuzzy sets is more compatible with linguistic and sometimes ambiguous human explanations. Therefore, it is better to use long-term predictions and real-world decisions using fuzzy numbers. Each triangular fuzzy number consists of three parameters

$F = (l \cdot m \cdot u)$. The upper bound (u) is the maximum value that a fuzzy number F can take. The lower bound (l) is the minimum value that a fuzzy number can take, and m is the most probable value of a fuzzy number.

$$\mu_F(x) = \begin{cases} \dfrac{x-l}{m-l}, & l < x < m, \\ \dfrac{u-x}{u-m}, & m < x < u, \\ 0, & \text{otherwise.} \end{cases} \quad (1)$$

In this weighting step, the sum of triangular fuzzy numbers is obtained according to the following formula:

$$\begin{aligned} F_1 &= (l_1 \cdot m_1 \cdot u_1), \\ F_1 + F_2 &= (l_1 + l_2 \cdot m_1 + m_2 \cdot u_1 + u_2), \\ F_2 &= (l_2 \cdot m_2 \cdot u_2). \end{aligned} \quad (2)$$

After collecting the criteria and evaluating them, the experts evaluated the criteria fuzzy (VH, H, M, L, VL). Then, the obtained fuzzy numbers were defuzzified, and the weights of the indicators were calculated and normalized.

2.2. Entropy Method. In this research, the entropy method has been used to determine the weight of the criteria. Entropy is used for calculating the weight of criteria. This method requires a criterion-option matrix. This method was proposed in 1974 by Shannon and Weaver [16]. Entropy represents the amount of uncertainty in a continuous probability distribution. The basic idea of this method is that the higher the scatter in the values of a criterion, the more important that criterion. First, the values of each cell of the matrix by the sum of the column values (simple normalization) are divided.

$$n_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}. \quad (3)$$

The entropy value of characteristic j is calculated as follows:

$$E_j = -K \sum_{i=1}^{m} n_{ij} \ln(n_{ij}), \quad k = \frac{1}{\ln m}, \quad (4)$$

where M is the number of options.

Using (E_j), the values of d_j for each characteristic are calculated:

$$d_j = 1 - E_j. \quad (5)$$

By normalizing the values ofd_j, the characteristic weight is obtained:

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j}. \quad (6)$$

After weighing the criteria, problem options (crisis management candidate locations in the region) are prioritized using the MOORA method.

2.3. MOORA Method. MOORA is a multiobjective decision-making method introduced by Brauers and Zavadskas in 2006 [17]. In 2010, Azar and Rajabzadeh improved the method and added the complete multiplication form to it [18]. The steps for applying this method in the problems are as follows:

Step 1. The first step in the MOORA method is to construct a decision matrix for the problem. The criteria (goals) and options are listed in the column and row of the decision matrix, respectively. The decision matrix shows the performance of different options according to different criteria.

$$\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \dots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}. \quad (7)$$

Step 2. Normalizing each column as follows:

$$n_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}^2}, \quad \forall j. \quad (8)$$

Step 3. Creating a harmonic decision matrix like the TOPSIS method, the weight of each criterion is multiplied by the normal decision matrix, and then a balanced normal decision matrix is formed.

Step 4. Selecting the optimal option from the following formula:

$$y_i = \sum_{j=1}^{g} w_j x_{ij}^* - \sum_{j=g+1}^{n} w_j x_{ij}^*, \quad (j = 1, 2, \dots, n). \quad (9)$$

2.4. PROMETHEE Method. The PROMETHEE 1 method performs a partial ranking, and the PROMETHEE 2 method performs a complete ranking. It was first developed by Brans in 1982 and was widely used in the early years [19]. A few years later, two new versions of PROMETHEE, PROMETHEE 3 (ranking by time intervals), and PROMETHEE 4 (continuous case) were developed [20]. One of the important advantages of the PROMETHEE method is the simplicity, clarity, and reliability of results. This method can perform the evaluation process on a limited set of alternatives as a partial or complete ranking. Suppose A is a set of options from which to choose. Assume there is an effective K criterion in the decision, $A \in a$; for each option, $F_j(a)$ represents the value of the criterion j in option a. Ranking is done in three steps as follows:

Step 1. P_j the preference function is assigned to each of the jth criteria. The value of $Pj(a, b)$ is calculated for each option pair. If the relation $F_j(a) = F_j(b)$ is established, the value of $P_j(a \cdot b)$ becomes zero, and with increasing $F_j(a) = F_j(b)$, this value increases, and when the difference is equal to 1, if it increases enough, the value of $P_j(a \cdot b)$ also reaches one. Different shapes can be assumed for the $P_j$function, depending on how the jth criterion is modeled. The PROMETHEE method proposes six generalized criteria for the preference function to the decision-maker.

Step 2. The total preference $\pi(a.b)$ for each action is calculated on action (b). Although $\pi(a.b)$ is higher, action (a) is more preferable. $\pi(a.b)$ is calculated as follows [21]:

$$\pi(a.b) = \sum_{j=1}^{K} wjpj(a.b).\left(\sum_{j=1}^{K} wj = 1\right). \quad (10)$$

Step 3. $\pi(a.b)$ indicates the degree of preference of action (a) over action (b) [21, 22]. $\varnothing^{+}$ is a positive current obtained from (11) and examines the degree of preference of (a) over $n-1$ of the other action. This is the amount of power of action (a). The positive preference flow or output current is as follows:

$$\varnothing^{+}(a) = \frac{1}{n-1}\sum_{x\epsilon A}\pi(x.a). \quad (11)$$

This flow indicates the priority of option (a) over other options. The preference of other options over option (a) is called input flow. The negative preference flow or input flow is as follows:

$$\varnothing^{-}(a) = \frac{1}{n-1}\sum_{x\epsilon A}\pi(x\cdot a). \quad (12)$$

This quantifies how a given action (a) is being globally preferred by all the other actions. The smallest negative flow $\varnothing^{-}(a)$ represents the best action [23]. For the complete ranking of options, the net flow of ranking options is considered [23]:

$$\varnothing(a) = \varnothing^{+}(a) - \varnothing^{-}(a). \quad (13)$$

The net flow score $(\varnothing(a))$ is computed as a difference between the positive flow and negative flow.

3. Proposed Approach and Problem Statement

In this research, a set of standard criteria for optimal location of relief centers as evaluation intervals and information layers in ArcGIS have been prepared. The weighting of criteria in the first phase was done by experts using the triangular fuzzy aggregation method. Then, the information layers are combined once by applying the weight of criteria and once without applying weight, and the optimal points are extracted. The Raster Calculator tool is used to merge layers so that all the layers were first gathered together and the final weightless map was produced. In the next step, we have multiplied each of the produced raster maps by their weight and combined them. Each point (weighted and nonweighted) is evaluated and scored against the criteria by GIS. After locating the proposed areas by GIS and observing unusable places in crisis (military centers and residential areas), in the next phase, 30 points of places were designated by the regional crisis management as post-crisis relief centers and identified by the GIS, and the problem was evaluated according to standard criteria. Then, the criteria were weighted by the entropy method, and the options were ranked by the MOORA method. Finally, due to the net input and output flows and the addition of constraints, optimal and efficient options were introduced. The performance of each of the options (options extracted by the GIS and selected options in the region) was evaluated according to their performance score. Due to incompatibilities between some research options, it may not be logical and possible to select some options at the same time. For this reason, there are 9 constraints for choosing the final optimal options. In this research, 2 constraints for the minimum and maximum options for selecting relief places and 7 other constraints for observing the standard distance set by experts have been considered. Figure 1 shows the general structure of the research.

In this study, after determining and evaluating the criteria, their weighting was done by the fuzzy aggregation method (by experts) and entropy method (point output information matrix) to determine the effect of each method on the results. Candidate points of the region extracted by the MOORA rank method were compared with the top points extracted from the GIS by the PROMETHEE method. This comparison was performed to evaluate and analyze the performance of each method to select relief centers in crises.

4. Case Study

The city of Tehran, located in the foothills of the Alborz Mountains range, has a high seismic risk and many active faults. Region 1 is located in the north and northeast of Tehran. This area is about 60 square kilometers. Relief centers are being set up to house the victims and people who lost their homes during the crisis. One of these crises is earthquakes. One of the secondary effects of earthquakes is liquefaction [24]. Liquidation causes severe damage to many structures, especially buildings [25]. The Japan International Cooperation Agency (JICA) has researched the Tehran earthquake. They have identified four-fault models that cause a lot of damage and loss, including the Ray fault model, Mosha fault model, North Tehran fault model, and floating model. One of the most important faults in the region is a North Tehran fault (more than 90 km). North Tehran fault, the northern part of the city, is facing many seismic hazards and damages because the fault is located on the northern outskirts of the city. According to research by JICA, in North Tehran fault, in the worst case, 130,000 people or about 2% of Tehran's population will be killed. The loss ratio in the northern part of the city will be high in areas 1 to 5. Also, the number of damages to buildings in this area is estimated at more than 60,000 buildings according to four fault models [26]. Therefore, in this research, we try to identify and evaluate the optimal places and areas for housing in crises. Table 1 shows the number and percentage of damage to buildings in area 1 based on each of the models [26].

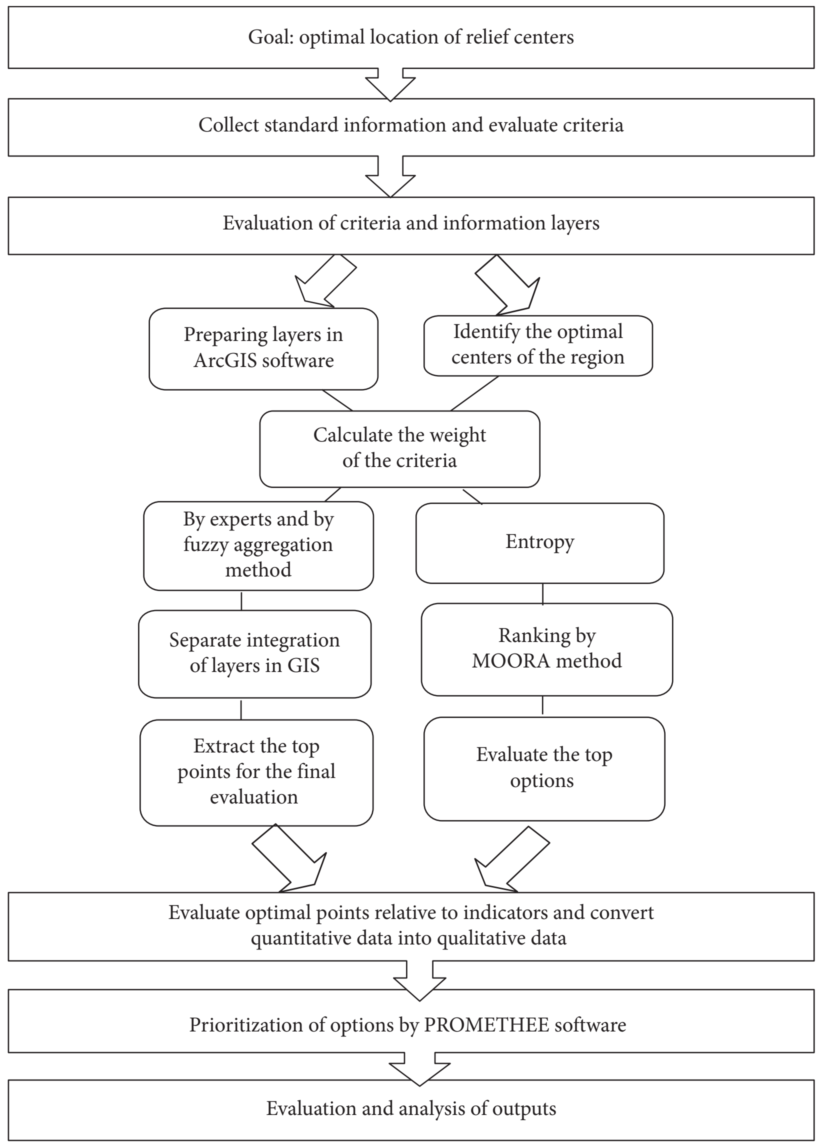

Figure 1: A schema of the proposed framework.

Table 1: Number and percentage of damages to buildings in Region 1.

Region	Floating model		Mosha fault model		North Tehran fault model		Ray fault model		Total number of damaged buildings
	Percentage	Number of buildings	Percentage	Number of buildings	Percentage	Number of buildings	Percentage	Number of buildings	
1	51.9	19.905	17.9	6.869	61.6	23.633	30.4	11.665	62.072

5. Data and Results

Criteria based on previous studies and classification of these criteria have been considered in collaboration with crisis management experts. The research criteria are shown in Table 1, which are defined in two parts (compatible access and incompatible access). The evaluation criteria are as follows:

(1) Standard mode of each criterion in the range (Good)

(2) Better than the standard mode in the range (Very good)

(3) A little away from the standard mode in the range (Average)

(4) Slightly longer than standard in (Bad) range

(5) If it is too far from the standard range, it is in the (Very bad) range

Table 2 shows the classification and evaluation of criteria.

Table 2: Classification and evaluation of criteria for locating relief centers in crises.

	C	*A*				
		Very good	Good	Average	Bad	Very bad
Compatible access	Area	3000	2000–3000	2000	1000–2000	0–1000
	Worn texture	0–100	100–200	200–300	300–400	400
	Main ways	0–100	100–200	200–300	300–400	400
	Security	0–200	200–400	400–600	600–800	800
	Slope percent	1–4	4–6	6–10	10–12	+12
	Hospital	0–500	500–1000	1000–1500	1500–2000	2000
	Fire station	0–500	500–1000	1000–1500	1500–2000	2000
	Population	120	90–120	60–90	30–60	0–30
	Health centers	0–200	200–500	500–700	700–1000	1000
	Educational centers	0–150	150–300	300–500	500–700	700
	Parks and gardens	0–200	200–400	400–600	600–1000	1000
Incompatible access	City gas station	400	200–400	100–200	50–100	0–50
	CNG and fuel station	400	200–400	100–200	50–100	0–50
	Wells and aqueducts	300	200–300	100–200	50–100	0–50
	Electric post	100	80–100	60–80	30–60	0–30
	Subway	300	200–300	100–200	50–100	0–50
	Fault	400	200–400	200	100–200	0–100
	Rivers	700	500–700	200–500	100–200	0–100

Table 3 shows the corresponding triangular fuzzy scale, and Table 4 presents the fuzzy opinions of experts, respectively. Also, the calculated weight of the criteria is given in Table 5, where the highest weight is related to the indicators of proximity to hospitals, medical centers, and worn tissue (1.0) and the lowest weight is related to the indicators of proximity to educational centers and surface area (0.7).

Table 3: Linguistics variables of fuzzy for the weight of each criterion.

VH	0.75	1	1
H	0.5	0.75	1
M	0.25	0.5	0.75
L	0	0.25	0.5
VL	0	0	0.25

5.1. Layer Valuation and GIS Output Evaluation. A Geographic Information System (GIS) is a coherent system of hardware, software, and data that allows data entered into a computer to be stored, analyzed, transferred, evaluated, and retrieved as a map, tabular, and zoned information geographies to be published. With the help of GIS, all kinds of processing and analysis can be done with cost and time savings [27]. GIS, with its capabilities in collecting, storing, retrieving, controlling, processing, analyzing, modeling, and displaying geographic data, can be a powerful tool in the hands of managers and planners for optimal use of resources [28]. In this study, the information layer was stored using the capabilities of the GIS. For uniformity and impact, the layers are evaluated as numerical intervals based on the buffer created in ArcGIS software. The following maps including a map of distance to the river (Figure 2), map of slope percentage (Figure 3), map of population density (Figure 4), map of distance to the gas station (Figure 5), map of distance to parks (Figure 6), and map of distance to the fire station (Figure 7) are an example of the criteria layers related to this research.

Figure 8 shows the favorable and unfavorable areas of the region for the establishment of relief centers. The blue area indicates favorable areas, and the red area indicates unfavorable areas.

After weighing the criteria, using GIS, and preparing information layers, first, the layers are matched without applying the weight of the indicators, and in the next step by

Table 4: Evaluated matrix of research criteria by experts.

	TM1			TM2			TM3		
Area	0.25	0.5	0.75	0	0.25	0.5	0	0.25	0.5
Main ways	0.5	0.75	1	0.25	0.5	0.75	0.5	0.75	1
Security	0.5	0.75	1	0.75	1	1	0.5	0.75	1
City gas station	0.25	0.5	0.75	0.25	0.5	0.75	0.5	0.75	1
CNG station	0.25	0.5	0.75	0.25	0.5	0.75	0.5	0.75	1
Percent slope	0	0.25	0.5	0.25	0.5	0.75	0.5	0.75	1
Hospital	0.5	0.75	1	0.75	1	1	0.75	1	1
Fire station	0.25	0.5	0.75	0.25	0.5	0.75	0.25	0.5	0.75
Electricity post	0.25	0.5	0.75	0.25	0.5	0.75	0.75	1	1
Population	0.25	0.5	0.75	0	0.25	0.5	0.25	0.5	0.75
Subway	0.25	0.5	0.75	0.25	0.5	0.75	0.5	0.75	1
Fault	0.75	1	1	0.5	0.75	1	0.5	0.75	1
Health centers	0.5	0.75	1	0.75	1	1	0.75	1	1
Rivers	0.5	0.75	1	0.5	0.75	1	0.25	0.5	0.75
Educational centers	0	0.25	0.5	0	0.25	0.5	0.25	0.5	0.75
Parks and gardens	0.25	0.5	0.75	0.25	0.5	0.75	0.25	0.5	0.75
Wells and aqueducts	0	0.25	0.5	0.25	0.5	0.75	0.25	0.5	0.75
Worn texture	0.5	0.75	1	0.75	1	1	0.75	1	1

Table 5: Weight of criteria obtained by experts.

Criteria	Weight	Final normal weight
Area	0.33	0.4
Main ways	0.67	0.8
Security	0.78	0.9
City gas station	0.58	0.7
CNG station	0.58	0.7
Percent slope	0.50	0.6
Hospital	0.83	1.0
Fire station	0.50	0.6
Electricity post	0.58	0.7
Population	0.42	0.5
Subway	0.58	0.7
Fault	0.78	0.9
Health centers	0.83	1.0
Rivers	0.67	0.8
Educational centers	0.33	0.4
Parks and gardens	0.50	0.6
Wells and aqueducts	0.42	0.5
Worn texture	0.83	1.0

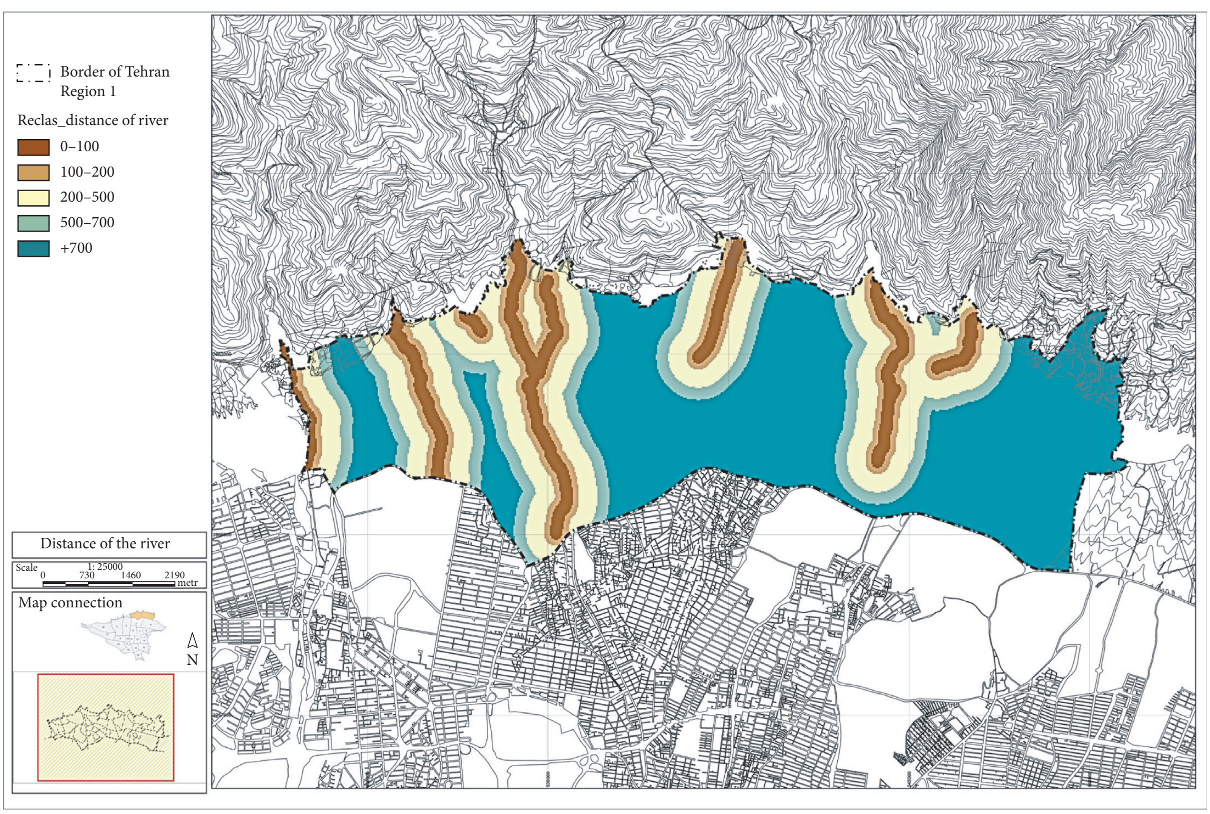

Figure 2: Distance to the river.

applying the weight of the indicators in ArcGIS software, the proposed optimal points among the optimal areas are extracted in the area. Figures 9 and 10 show the proposed points extracted for the construction of relief bases in both cases (by applying the weight of the criteria and without applying the weight of the criteria).

5.2. Evaluation and Feasibility of the Proposed Optimal Points. After combining the information layers and determining the proposed optimal points by the GIS, the proposed points are evaluated in terms of the location of each extracted optimal area relative to the indicators evaluated in Table 1. As shown in Figures 9 and 10, the proposed optimal points of the GIS

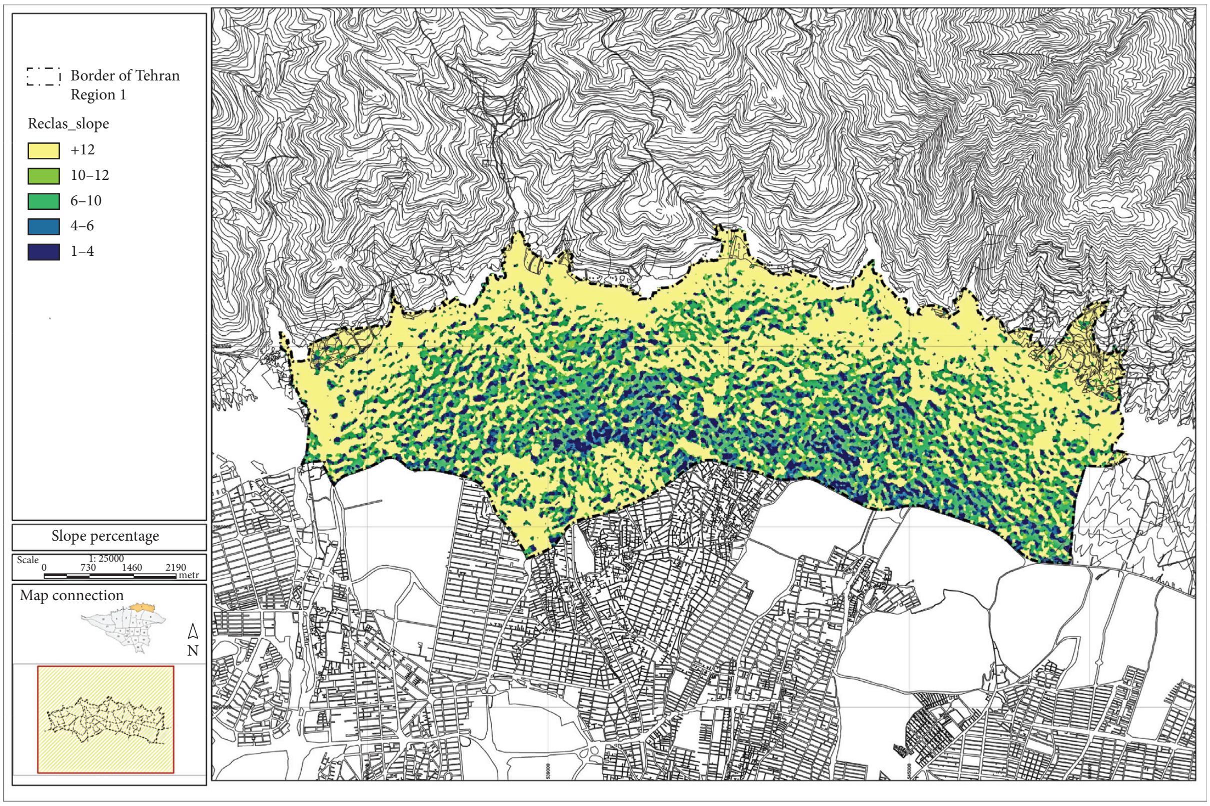

Figure 3: Slope percentage.

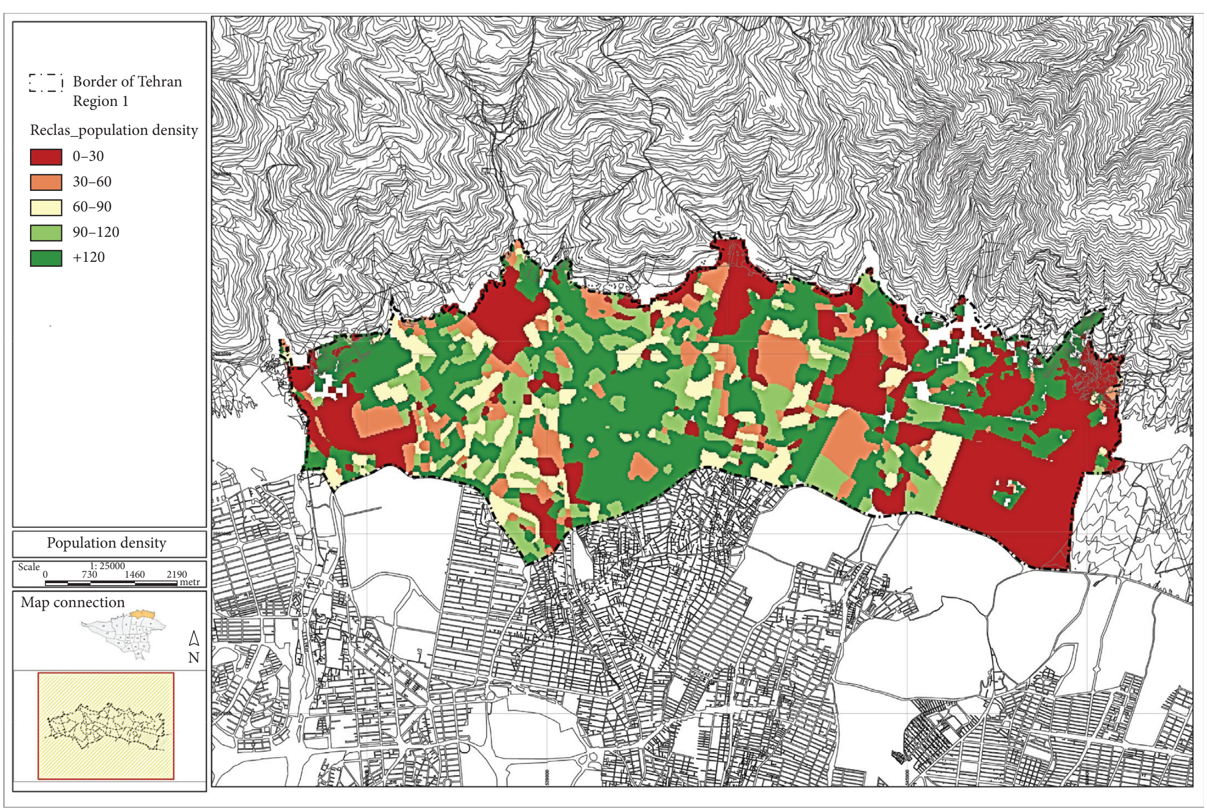

Figure 4: Population density.

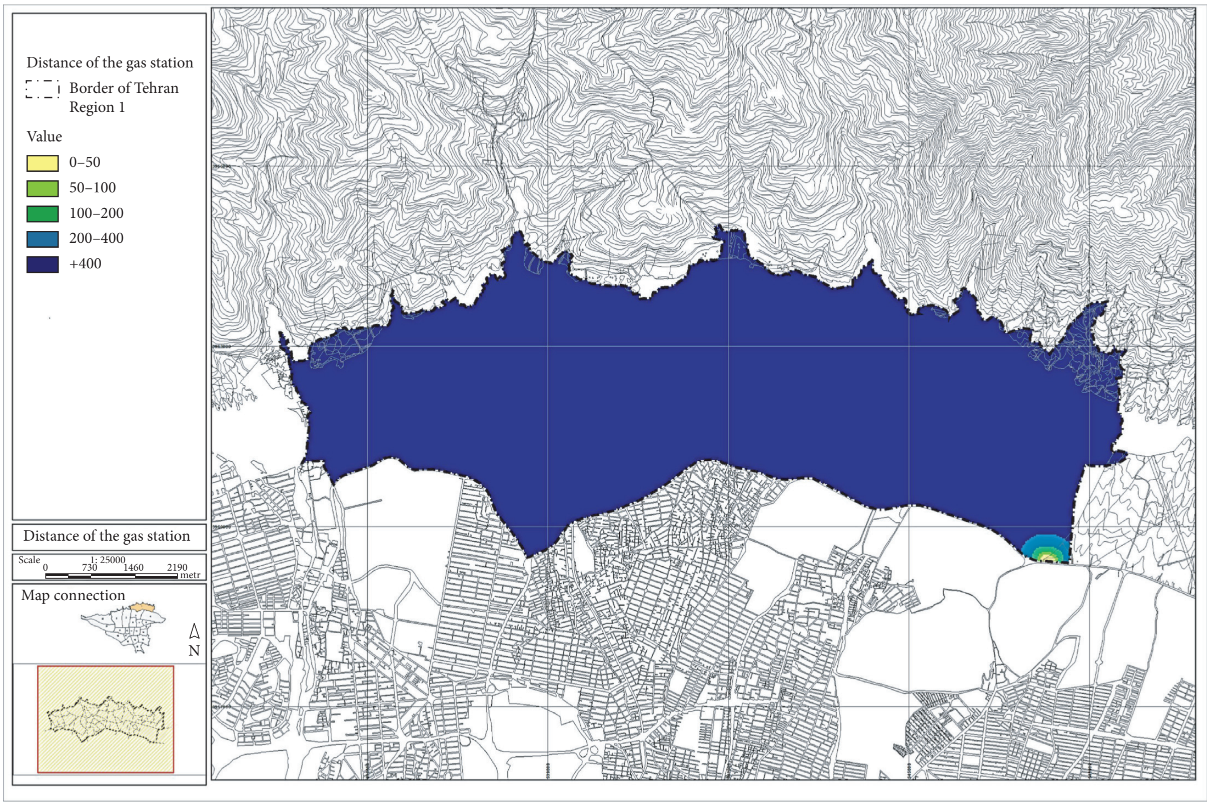

Figure 5: Distance to the gas station.

Figure 6: Distance to parks.

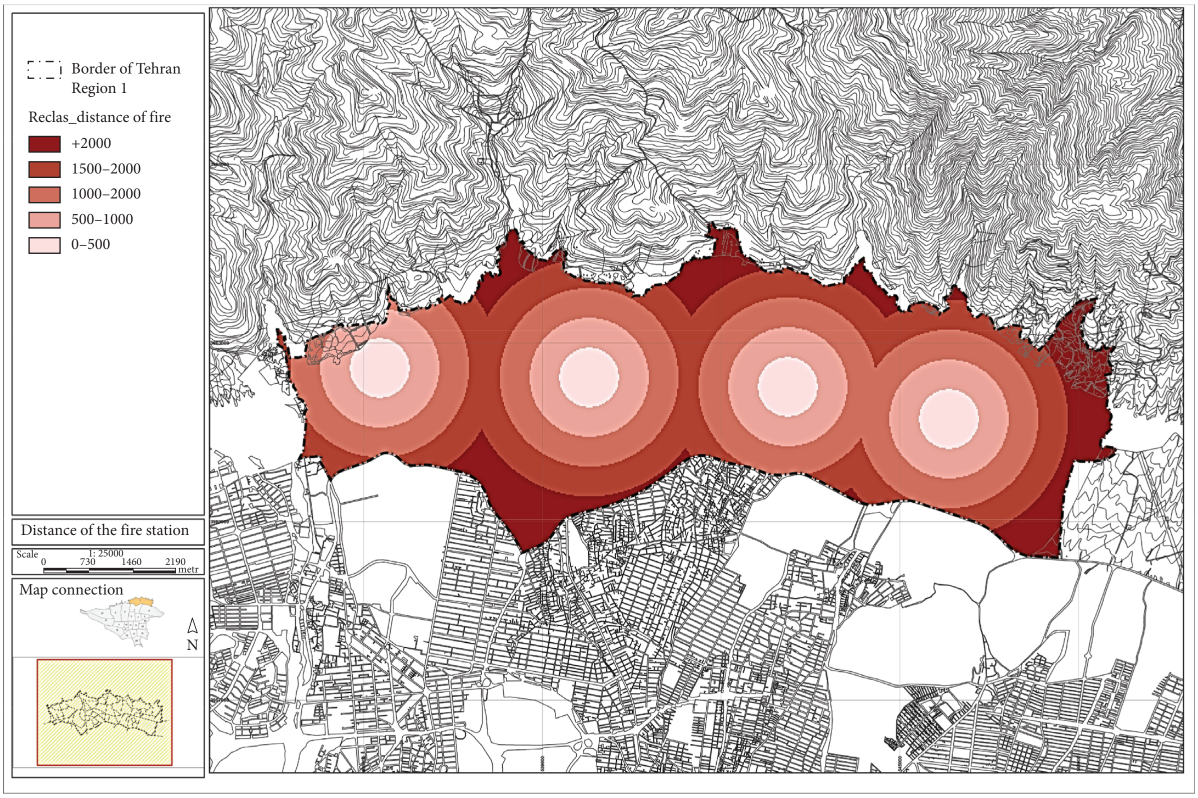

Figure 7: Distance to the fire station.

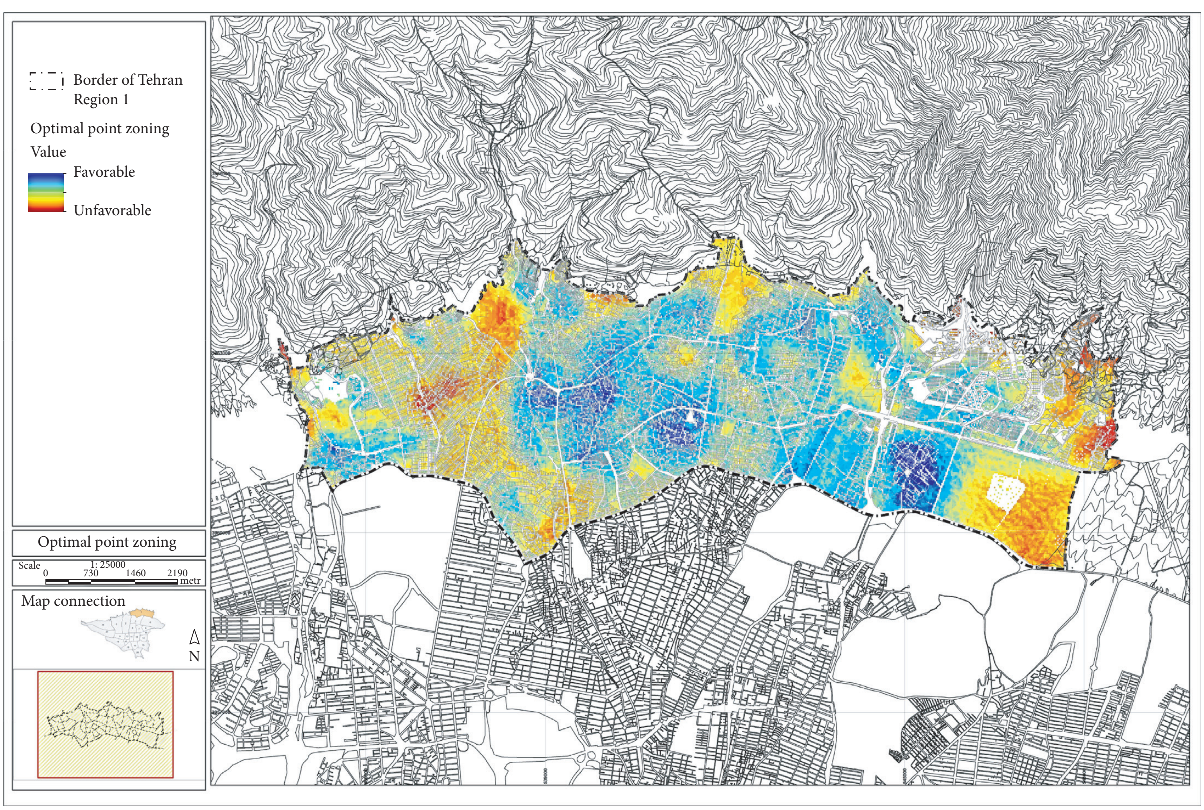

Figure 8: Favorable and unfavorable areas for the construction of relief centers.

Figure 9: Optimal areas extracted by GIS without applying weight.

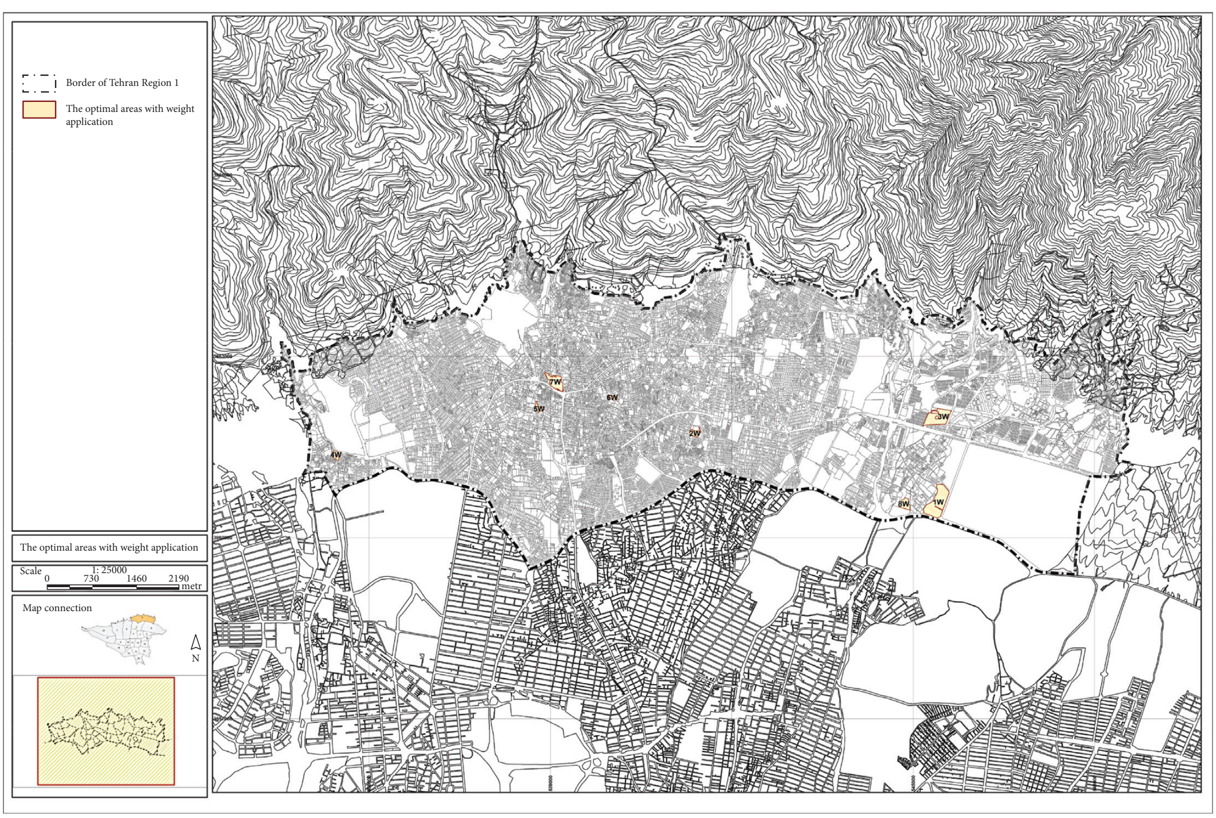

Figure 10: Optimal areas extracted by GIS by applying weight.

with the application of criteria weights (PW1, PW2, PW3, PW4, PW5, PW6, PW7, and PW8) and without the application of criteria weights (P1, P2, P3, P4, P5, P6, P7, and P8) are different. Table 6 shows the results of the evaluation of points without assigned weight (eight optimal regions obtained in Figure 9), and Table 7 shows the results of the evaluation of points with assigned weight (eight optimal regions obtained in Figure 10). For example, the results of evaluating the optimal points extracted without applying weights (see Figure 9) to the distance criteria from the fault were as follows: points p1, p2, p3, p4, p7, and p8 in the range above 400 m, and point p6 and p5 in the range of 400–200 were placed. Also, the results of evaluating the optimal points introduced by applying the weight of the indicators (see Figure 9) were as follows: PW1, PW2, PW3, PW4, and PW8 in the range above 400 meters, and PW5 and PW6 in the range of 400–200 and PW9 in the range of 0–100 were placed. The evaluation results of other optimal points extracted are shown in Tables 6 and 7.

Afterward, the criteria have been qualitatively evaluated (Very bad; Good; Average; Bad; Very good). Very good has the highest score and Very bad has the lowest score. Each of these points (points with the weight of experts and points without the weight of experts) is placed in one of the scoring points after evaluation by the GIS. For example, point PW1, after evaluation by the Geographic Information System (GIS), is in the range of 0–200 in terms of security criteria, which according to the classification considered in Table 2 is qualitatively in the range of Very good. Also, if we examine point P1 with the same criteria, it is shown in Table 6 that this point is in the range of 200–400, which according to the classification considered in Table 1 will be in the range of Good.

5.3. Feasibility Study of the Proposed Areas of the GIS and Relief Centers in the Case Study. Using Google Earth, the output of the optimal areas proposed for the establishment of relief centers in times of crisis has been examined (see Figure 11). As can be seen in Figures 12 and 13, some of the selected areas of the GIS (optimal proposed areas of Figures 9 and 10) have been military or residential. It will not be possible to use these places as postcrisis relief centers.

Usually, after an earthquake, to create safe conditions for residents and citizens and get them out of dangerous conditions, safe evacuation operations are carried out. Safe evacuation centers include all safe evacuation sites and spaces where people can be accommodated if needed. They use basic facilities to meet their needs (for 72 hours). The Tehran Crisis Management Organization has identified suitable locations in all 22 districts of Tehran to use these shelters in times of crisis. Figure 14 shows the location of these places, which are mostly stadiums and parks in the area.

6. Evaluation of Calculation Results

Then, 30 locations determined by Tehran Crisis Management in the study area were identified and evaluated by the GIS according to the standard criteria of this study (Table 2). Most of these places are stadiums, universities, and parks that cover almost all parts of the region. The results of the evaluation of these places by the GIS are shown in Table 8.

After evaluating 30 relief sites considered by the regional crisis management and forming a pairwise comparison matrix, the criteria were weighted and then prioritized. Table 9 shows the weight of the criteria calculated by the entropy method. As can be seen in Table 9, the criterion of distance from the river and distance from the main roads has the highest weight (0.0589, 0.0576) and the criteria of worn texture and land slope have the lowest weight (0.0470, 0.0514).

Problem options are prioritized according to the MOORA method (see Table 10). As can be seen, the performance score (Yi) of Morvarid Park, Gol Mohammadi Park, and Negin Park is higher than that of other options, so these options ranked first to third.

After ranking the proposed locations in the area for temporary accommodation, the top eight locations were selected and quantitative values were converted to qualitative (according to the information in Table 2) to compare and evaluate these options with the proposed optimal points of GIS. After evaluating the proposed areas by GIS in both modes (with the weight of experts and without the weight of experts) and the places determined by the Crisis Management of Region 1, the final optimal options with the PROMETHEE method were compared and evaluated. In the options evaluation step, the obtained qualitative values are considered a pairwise comparison matrix for options and criteria. Table 11 shows the result of flow evaluation, which shows the values of positive $\varnothing^{+}$, negative $\varnothing^{-}$, and net $\varnothing$ Flows. As can be seen in Table 11, P5 with a net flow of 0.1232, P6 with a net flow of 0.1208, and PW8 with a net flow of 0.1159 were ranked first to third in the PROMETHEE rankings. Also, Morvarid Park with a net flow of –0.1860, Shadi Park with a net flow of –0.1715, and Aseman Park with a net flow of –0.1570 had the worst performance. Table 11 shows the PROMETHEE ranking results of options.

In Figure 15, GAIA diagram shows the options. The length of an axis also indicates the relative strength of that criterion. A longer axis indicates a more important criterion. On the other hand, the direction of an axis indicates where the best possible options for this criterion are located. In the GAIA form, options that are similar to each other are closer to each other, and options that conflict with each other are farther apart. Criteria that have similar preferences are in the same direction, and criteria that have conflicting preferences are in different directions. For example, the PW1 option is in line with the percentage of slope and distance from worn texture, which shows good performance compared with these indicators. This option has performed very poorly in terms of the criteria of main roads, distance from the subway, and distance from parks (due to being in the opposite direction of these criteria). As can be seen, the proposed locations in the region are scattered and far from the axes of the criteria, and this poor performance has led to a lower ranking than other options.

Table 6: Evaluation of optimal points according to criteria (without applying normalized weight).

Optimal points	Criteria							
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
Area	More than 3000	More than 3000	More than 3000	More than 3000	More than 3000	More than 3000	More than 3000	More than 3000
Worn texture	More than 400	More than 400	200_300	0–100	100_200	100_200	100_200	More than 400
Main ways	0–100	200–300	200–300	0–100	0–100	100–200	100–200	100–200
Security	200–400	400–600	200–400	More than 800	200–400	0–200	200–400	0–200
Gas station	200–400	More than 400	More than 400	More than 400	More than 400	More than 400	More than 400	More than 400
CNG station	More than 400	More than 400	More than 400	More than 400	More than 400	More than 400	More than 400	More than 400
Percent slope	6–10	6–10	6–10	More than 12	More than 12	1–4	1–4	More than 12
Wells and aqueducts	200_300	More than 300	More than 300	More than 300	More than 300	More than 300	200_300	More than 300
Hospital	500_1000	500_1000	1000_1500	500_1000	500_1000	500_1000	1000_1500	500_1000
Fire station	1000_1500	0_500	1000_1500	1000_1500	0_500	0_500	1500_2000	500_1000
Electricity post	More than 100	More than 100	More than 100	More than 100	More than 100	More than 100	More than 100	More than 100
Population	More than 120	90–120	90_120	More than 120	More than 120	30_60	0_30	30_60
Subway	More than 300	50–100	More than 300	More than 300	More than 300	More than 300	More than 300	More than 300
Fault	More than 400	More than 400	More than 400	More than 400	200–400	200–400	More than 400	More than 400
Health centers	More than 1000	700–1000	0–200	200–500	700–1000	700–1000	0–200	More than 1000
Rivers	More than 700	500_700	More than 700	200_500	More than 700	More than 700	More than 700	More than 700
Educational centers	0_150	0_150	150_300	150_300	300_500	300_500	0_150	500_700
Parks and gardens	0_200	0_200	0_200	0_200	0_200	0_200	0_200	0_200

Among the research criteria, incompatible access criteria (criteria in Table 2) must observe the standard distance set by crisis management experts. For example, relief centers must be 400 meters away from the city gas station; otherwise, they will not be eligible for use as relief centers (even if they perform well in other criteria). PROMETHEE V selects the optimal options based on a 0-1 linear program in which the objective function maximizes the sum of the net flow points (Phi). For each constraint, it is possible to enter the coefficients and specify the type of constraint (≤, = or ≥). Table 12 sets the limits and shows the optimal options offered by PROMETHEE V. The "Optimal" column displays the optimal solution. The "Total" rows show the value of the objective function (i.e., the sum of the net flow scores of the selected actions) for both selections. PROMETHEE V offers P1, P2, P3, P5, P6, PW1, PW2, PW3, PW4, PW6, PW8, and Niavaran Park as optimal options for the overall flow of 0.8671.

Figure 16 shows the efficiency of research options. This figure is a two-dimensional representation of the input and output flows. An efficiency frontier is drawn in red. Efficient options with different functions are on the line. Higher net flows of an action's outputs and lower net flows of its inputs are better. For instance, option PW7 has a high input flow and higher output flow. The other actions lag behind the efficient frontier. Finally, considering the amount of net flow (∅) and the performance score obtained for each of the options, the overall performance of the options in each optimal location extraction method is evaluated and shown in Figure 17. As can be seen, the performance of points without applying weights is 37% and with applying weights is 36% and the performance of places designated by crisis management is 27%. The reason for the poor performance of the places in the region can be considered their poor performance in some standard criteria such as distance to main roads, distance to the river, and safety, which have been among the important criteria of the issue. The difference between optimal options and efficient options is in their evaluation process. The basis of the PROMETHEE V rating is the full rating (PROMETHEE II), which, by adding additional constraints to the multicriteria net flow rating f (Phi), provides a global assessment of the measures taking into account all criteria. Efficient options are the result of comparing the input and output streams of the criteria classification. This is similar to the input/output model used in data envelopment analysis (DEA). When measuring the

Table 7: Evaluation of optimal points according to the criteria (by applying normalized weight).

Optimal points	Criteria							
	P_{W1}	P_{W2}	P_{W3}	P_{W4}	P_{W5}	P_{W6}	P_{W7}	P_{W8}
Area	More than 3000	More than 3000	More than 3000	More than 3000	More than 3000	More than 3000	More than 3000	More than 3000
Worn texture	More than 400	100–200	0–100	0–100	100–200	0_100	0_100	More than 400
Main ways	200_300	100–200	200_300	0–100	200_300	100_200	100_200	100_200
Security	0–200	200–400	600–800	More than 800	400–600	200–400	0–200	0–200
Gas station	More than 400	More than 400	More than 400	More than 400	More than 400	More than 400	More than 400	More than 400
CNG station	More than 400	More than 400	More than 400	More than 400	More than 400	More than 400	More than 400	More than 400
Percent slope	6_10	1_4	6_10	More than 12	6_10	1_4	6_10	1_4
Wells and aqueducts	More than 300	200–300	More than 300	More than 300	More than 300	More than 300	More than 300	More than 300
Hospital	1000_1500	1000_15000	500_1000	500_1000	0_ 500	500_1000	0_ 500	500_1000
Fire station	1000_1500	1500–2000	1000–1500	1000_1500	1000_1500	0_500	500_1000	1000_1500
Electricity post	more than 100	more than 100	more than 100	more than 100	more than 100	more than 100	0_30	more than 100
Population	90_120	0–30	90_120	More than 120	60_90	30_60	0_30	0_30
Subway	More than 300	More than 300	More than 300	More than 300	More than 300	More than 300	0_50	More than 300
Fault	More than 400	More than 400	More than 400	More than 400	400–200	400–200	0_100	More than 400
Health centers	0_200	0–200	700–1000	200_500	200_500	700_1000	200_500	200_500
Rivers	More than 700	More than 700	500–700	200_500	0_100	More than 700	0_100	More than 700
Educational centers	150_300	0_150	0_150	150_300	150_300	300_500	150_300	150_300
Parks and gardens	200–400	0_200	0_200	0_200	0_200	0_200	0_200	200_400

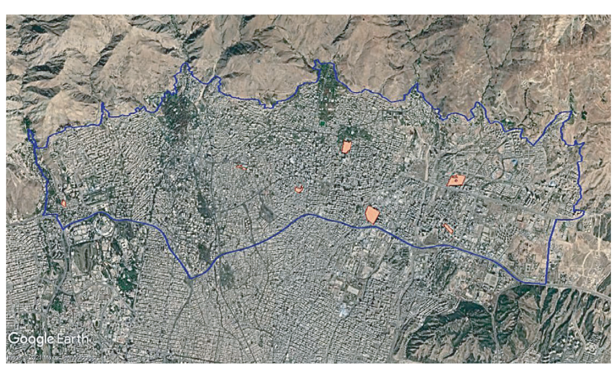

Figure 11: Optimal areas extracted by GIS in the zone.

efficiency of operational units (or DMUs—decision-making units—in the DEA), it is common to compare input criteria (different resources allocated to the units) to output criteria (results generated by the activity of the units) and to look for some kind of "best" output/input ratio [29, 30]. Suppose we have n DMUs, where DMUj ($j = 1, \ldots, n$) uses m inputs x_{ij}

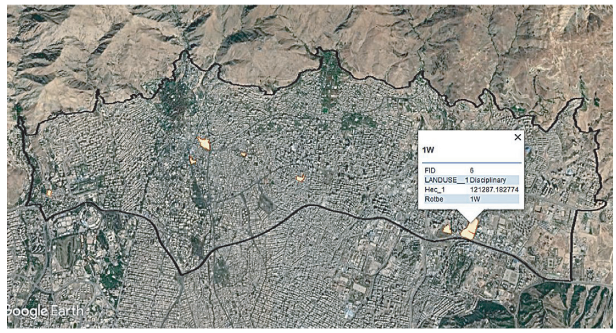

Figure 12: Military area (one of the optimal output areas of GIS).

Figure 13: Residential area (one of the optimal output areas of GIS).

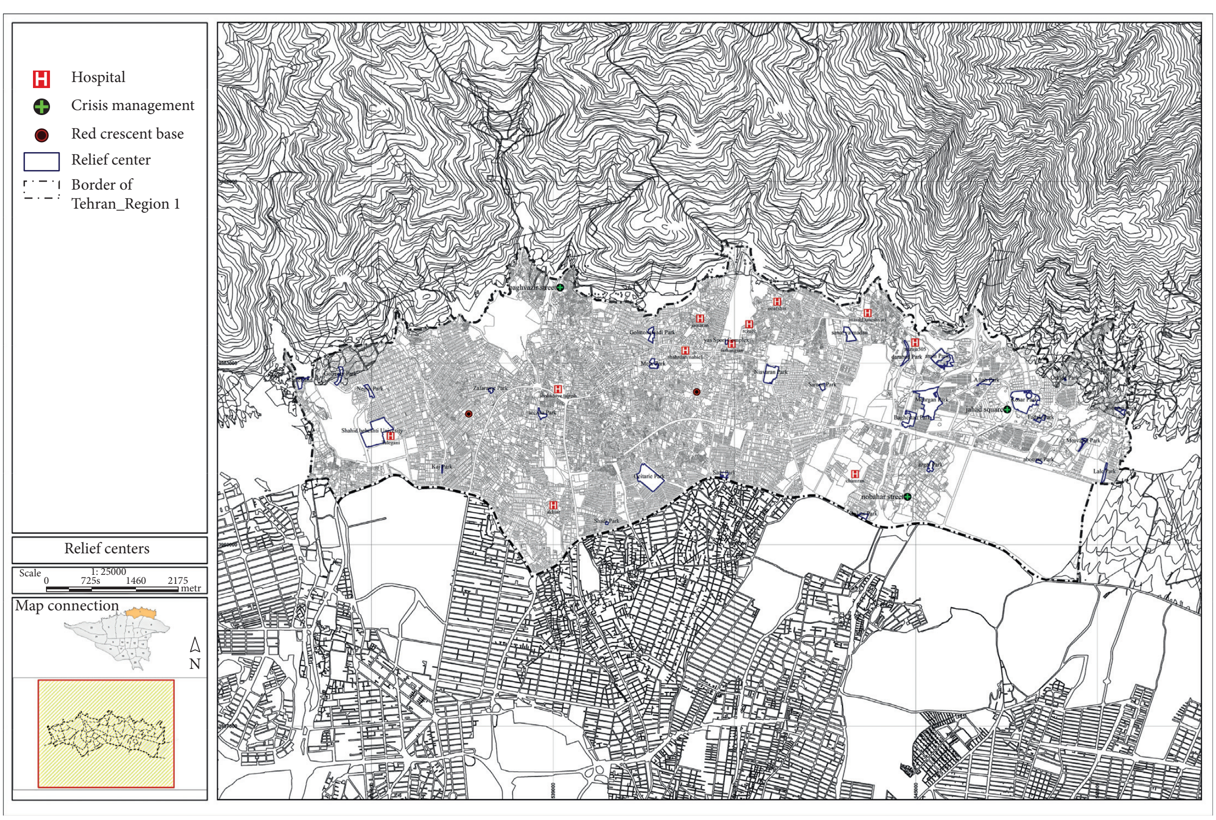

Figure 14: Relief centers for crisis accommodation in area 1.

Table 8: Evaluation results of places in the region.

Optimal points	Criteria																
	Area	Worn texture	Main ways	Security	City gas station	CNG station	Slope percent	Wells and aqueducts	Hospital	Fire station	Electricity post	Population	Subway	Fault	Health centers	Rivers	Educational centers	Parks and gardens
Laleh Park	VG	VB	VG	G	VG	VG	A	G	VB	VB	VG	VB	VG	VG	VB	VG	VB	VG
Aseman Park	VG	VG	VG	VB	VG	VG	VB	VG	VB	VB	VG	VB	VG	VG	VB	VG	VB	VG
Morvarid Park	VG	VB	VG	A	VG	VG	VB	VG	VB	VB	VG	VB	VG	VG	VB	VG	B	VG
Aboozar Park	VG	VB	VG	VG	VG	VG	B	VG	VB	A	VG	VB	VG	VG	VB	VG	VG	VG
Fadak Park	VG	VB	G	A	VG	VG	VB	VG	VB	A	VG	VB	VG	VG	VB	VG	VG	VG
Orchid Garden	B	VB	VG	VB	VG	VG	VB	VG	VB	VB	VG	VG	VG	VG	VB	VG	VG	VG
Kowsar Park	VG	VB	VG	G	VG	VG	VB	VG	B	A	VG	VB	VG	VG	VB	VG	VG	VG
Golzar Park	VG	VB	VG	VG	VG	VG	VG	VG	A	VB	VG	VG	G	VG	B	VG	VG	VG
Ozgol Park	VG	VG	VG	VG	VG	VG	A	VG	A	G	VG	A	VG	VG	A	G	B	VG
Mehregan Park	VG	VB	VG	VG	VG	VG	VB	VG	VG	G	VG	A	VG	VG	VB	A	VG	VG
Aftab Park	VG	VB	VG	VG	VG	VG	VB	VG	A	G	VG	VB	VG	VG	VB	A	G	VG
Amin Park	VG	VB	A	B	VG	VG	VB	VG	VG	A	VG	VG	VG	VG	VB	A	A	VG
Baghestan Park	VG	VB	G	G	VG	VG	VG	VG	G	G	B	VB	A	VG	B	B	G	VG
Darabad Coastal Park	VG	VG	G	G	VG	VG	VB	VG	VG	VB	VG	B	VG	VG	VB	VB	VB	VG
Samen Park	VG	VB	G	G	VG	VG	A	VG	A	VG	VG	VG	VG	VG	VB	VG	VB	VG
Industry Sports Complex	VG	B	VG	G	VG	VG	VB	VG	VG	A	VG	VB	VG	VG	VB	G	VB	VG
Niavaran Park	VG	VB	VG	VG	VG	VG	VB	VG	G	G	VG	B	VG	VG	VB	VG	B	VG
Yas Sport Complex	VB	VB	G	G	VG	VG	VB	A	VG	VB	VG	VB	VG	VG	VB	B	VG	VG
Gol Mohammadi Park	VG	VB	VG	G	VG	VG	VB	VG	G	A	VG	G	VG	VG	VB	VG	VB	VG
Mehr Park	VG	VB	VG	A	VG	VG	VB	VG	G	A	VG	VB	VG	VG	VB	VG	G	VG
Sadr Park	VG	VB	VG	VB	VG	VG	VB	VG	B	VB	VG	A	VG	VG	B	VG	B	VG
Qeytarieh Park	VG	B	VG	VB	VG	VG	VB	VG	A	A	VG	B	VG	VG	B	VG	A	VG
Shadi Park	B	VB	G	VB	VG	VG	VB	VG	G	VB	VG	VG	VG	VG	VB	G	G	VG
Arezoo Park	VG	G	G	A	VG	VG	A	VG	VG	G	VG	A	VG	VG	G	VB	VG	VG
Zaferaniyeh Park	VG	VB	VG	B	VG	VG	VB	VG	G	VB	VG	A	VG	VB	VB	G	B	VG
Kaj Park	G	VB	VG	A	VG	VG	VB	VG	G	VB	VG	VG	VG	VG	VB	VB	VB	VG

Table 8: Continued.

Optimal points	Criteria																
	Area	Worn texture	Main ways	Security	City gas station	CNG station	Slope percent	Wells and aqueducts	Hospital	Fire station	Electricity post	Population	Subway	Fault	Health centers	Rivers	Educational centers	Parks and gardens
Beheshti University	VG	VB	VG	A	VG	VG	VB	VG	VG	G	VG	B	VG	VB	A	VG	A	VG
Golrizan Park	VG	VB	VG	B	VG	VG	VB	VG	A	G	VG	VG	VG	B	B	VG	G	VG
Negin Park	VG	VB	VG	VB	VG	VG	VB	VG	G	VG	VG	VG	VG	B	B	VG	VG	VG
Wasteland	VG	VB	G	VG	VG	VG	VB	VG	B	A	VG	VB	VG	VG	B	VB	VB	VG

Table 9: Weight of criteria calculated by the entropy method.

Criteria	W_j
Area	0.0559
Worn texture	0.047
Main ways	0.0576
Security	0.0556
City gas station	0.0575
CNG station	0.0575
Percent slope	0.0514
Wells and aqueducts	0.0573
Hospital	0.0561
Fire station	0.0542
Electricity post	0.0573
Population	0.0556
Subway	0.0573
Fault	0.0562
Health centers	0.0515
Rivers	0.0589
Educational centers	0.0556
Parks and gardens	0.0575

Table 10: MOORA method ranking results.

Rank	Options	Y_i
1	Morvarid Park	0.10128
2	Gol Mohammadi Park	0.10109
3	Negin Park	0.09347
4	Maher Park	0.09332
5	Kaj Park	0.0909
6	Orchid Garden	0.0891
7	Aboozar Park	0.0864
8	Sadr Park	0.08616
9	Kowsar Park	0.08504
10	Fadak Park	0.08453
11	Industry Sports Complex	0.0834
12	Golzar Park	0.08311
13	Aftab Park	0.08255
14	Zaferaniyeh Park	0.08222
15	Amin Park	0.08204
16	Shadi Park	0.08204
17	Ozgol Park	0.08167
18	Yas Sport Complex	0.08153
19	Arezoo Park	0.08134
20	Wasteland	0.07764
21	Samen Park	0.07725
22	Mehregan Park	0.07646
23	Darabad Coastal Park	0.07604
24	Aseman Park	0.06842
25	Baghestan Park	0.06321
26	Niavaran Park	0.06189
27	Shahid Beheshti University	0.06068
28	Golrizan Park	0.05907
29	Laleh Park	0.05538
30	Qeytarieh Park	0.03015

Table 11: The values of the flows calculated by the PROMETHEE method.

Actions	∅	$∅^{+}$	∅
P5	0.1232	0.2947	0.1715
P6	0.1208	0.3068	0.1860
PW8	0.1159	0.2633	0.1473
P4	0.0942	0.2633	0.1691
PW1	0.0870	0.2633	0.1763
P3	0.0821	0.2705	0.1884
PW6	0.0580	0.2947	0.2367
PW2	0.0531	0.2826	0.2295
P1	0.0386	0.2633	0.2246
PW4	0.0362	0.2609	0.2246
Niavaran Park	0.0362	0.2246	0.1884
PW3	0.0169	0.2657	0.2488
P2	0.0048	0.2609	0.2560
P7	−0.0048	0.2778	0.2826
PW5	−0.0072	0.2657	0.2729
P8	−0.0072	0.2029	0.2101
Mohammadi Park	−0.0145	0.1884	0.2029
PW7	−0.0290	0.2995	0.3285
Amin Park	−0.0894	0.1836	0.2729
Darabad Park	−0.0918	0.1860	0.2778
Qeytarieh Park	−0.1087	0.1812	0.2899
Aseman Park	−0.1570	0.1425	0.2995
Shadi Park	−0.1715	0.1498	0.3213
Morvarid Park	−0.1860	0.1256	0.3116

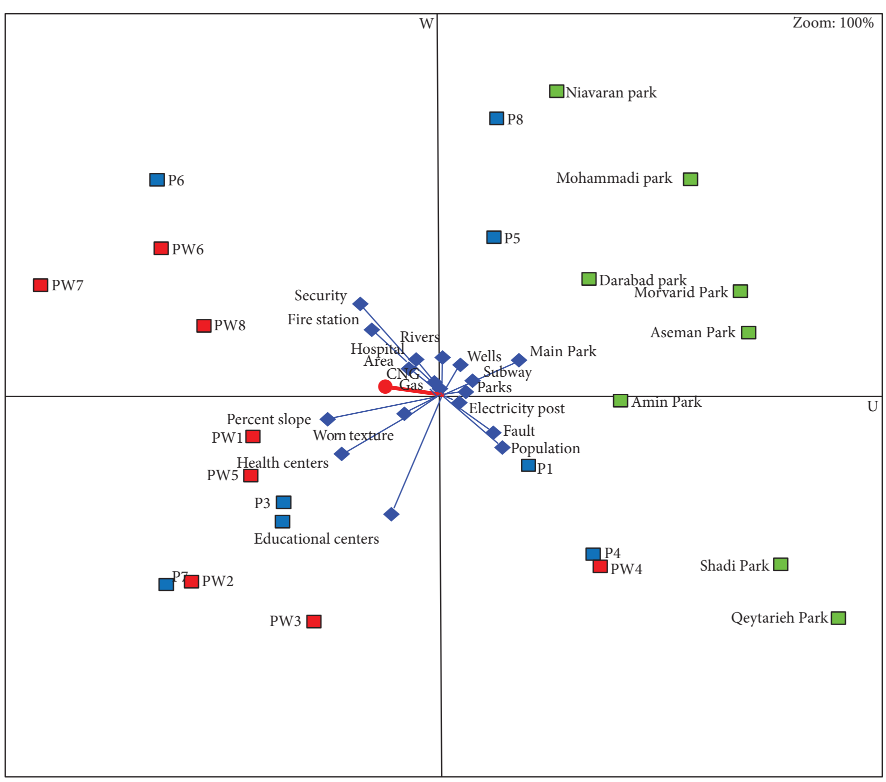

Figure 15: GAYA PROMETHEE diagram for analyzing criteria and options.

Table 12: Limitations and optimal options offered by PROMETHEE V.

Actions	Net flow	Optimal	Compare
	TOTAL	0.8671	0.8671
P1	0.0386	Yes	Yes
P2	0.0048	Yes	Yes
P3	0.0821	Yes	Yes
P4	0.0942	Yes	Yes
P5	0.1232	Yes	Yes
P6	0.1208	Yes	Yes
P7	−0.0048	No	No
P8	−0.0072	No	No
PW1	0.0870	Yes	Yes
PW2	0.0531	Yes	Yes
PW3	0.0169	Yes	Yes
PW4	0.0362	Yes	Yes
PW5	−0.0072	No	No
PW6	0.0580	Yes	Yes
PW7	−0.0290	No	No
PW8	0.1159	Yes	Yes
Aseman Park	−0.1570	No	No
Morvarid Park	−0.1860	No	No
Mohammadi Park	−0.0145	No	No
Darabad Park	−0.0918	No	No
Amin Park	−0.0894	No	No
Qeytarieh Park	−0.1087	No	No
Shadi Park	−0.1715	No	No
Niavaran Park	0.0362	Yes	Yes

Constraints	Optimal			Compare		
	LHS		RHS	LHS		RHS
Minimum	13.00	≥	1	13.00	≥	1
Maximum	13.00	≤	24	13.00	≤	24
Gas	18205	≥	400	18205	≥	400
CNG	147900	≥	400	147900	≥	400
Wells	10190	≥	50	10190	≥	50
Electricity post	22281	≥	30	22281	≥	30
Subway	16345	≥	50	16345	≥	50
Fault	9110	≥	100	9110	≥	100
Rivers	12680	≥	100	12680	≥	100

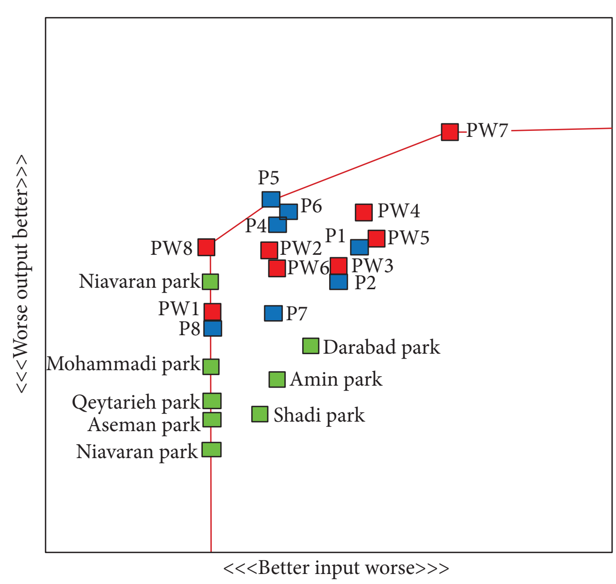

Figure 16: Performance of efficient options and inefficient options of research.

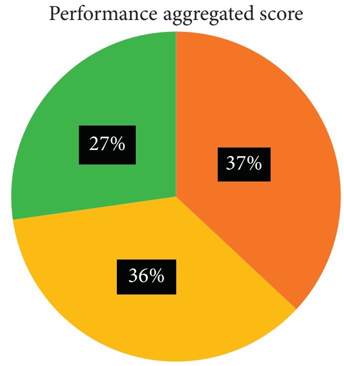

Figure 17: Comparing the overall performance of the options.

($i = 1, \ldots, m$) to produce s outputs y_{rj} ($r = 1, \ldots, s$). DEA uses the following model for evaluating kth DMU's efficiency (denoted byθ):

$$\min \theta \\ s.t: \sum_j \lambda_j x_{ij} \leq \theta x_{io}, \quad \forall i \sum_j \lambda_j y_{rj} \geq y_{ro}, \quad \forall r \lambda_j, \quad \theta \geq 0 \forall i, j, r. \tag{14}$$

7. Conclusion

In this study, the proposed locations of the Regional Crisis Management Organization and the proposed optimal points of the GIS according to 18 standardized criteria were evaluated. Also, by examining the feasibility of the optimal areas extracted by the GIS, the applicability or nonapplicability of the optimal areas introduced in crises has been addressed. The information layers were overlapped once by applying the criteria weight and once without applying the weight, and the optimal points were extracted. Each point (weighted and without weight) was evaluated and scored by GIS according to the indicators. In the next step, the designated crisis management locations in the study area are evaluated concerning the problem indicators and ranked by the MOORA method. By entering the qualitative information of the optimal location and points in the PROMETHEE method, each of the suggested points was evaluated. Finally, considering the amount of net flow (φ) and the performance score of each of the options and by applying constraints, the optimal and efficient options were determined. Limitations include the minimum and maximum options for selecting relief sites ranging from 1 to 24 options and restrictions that must meet the standard distance set by crisis management experts. The results showed good performance of areas without weight application (37%) and optimal areas with weight application (36%) compared with the proposed locations of the Regional Crisis Management Organization (27%) so that the results of the net flow performance analysis and the score of each of the options (see Figure 3) indicate the superiority of points without applying weights.

The reason for the closeness of the results of the GIS can be considered the reasonable opinion of experts. The noteworthy point of this research is the performance of the considered places in the region, which have not been very satisfactory. The difference in the performance of 10% of GIS output with the locations in the region can be considered the poor performance of these locations in some indicators. The performance of the places means the top eight places in the region (the top eight places in the MOORA ranking), but if we examine other places concerning these optimal places and standard criteria, we will see more worrying results. Also, by applying research limitations, it was found that only 13 out of 24 research options were optimal. According to the net input and output flows, the 14 options do not have the necessary performance for crises [31, 32].

Due to the high importance of location, especially the location of relief centers, and due to the high sensitivity of these centers, the use of more accurate and reliable methods should be a priority. It is recommended that managers and staff of the Regional Crisis Management Organization consider these places in terms of cost and economic criteria.

Data Availability

The data are available upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] F. Sabouhi, Z. S. Tavakoli, A. Bozorgi-Amiri, and J. B. Sheu, “A robust possibilistic programming multi-objective model for locating transfer points and shelters in disaster relief,” *Transportmetrica A: Transport Science*, vol. 15, no. 2, pp. 326–353, 2019.

[2] D. Guha-Sapir, F. Vos, R. Below, and S. Ponserre, *Annual Disaster Statistical Review 2011: The Numbers and Trends*, Centre for Research on the Epidemiology of Disasters (CRED), Brussels, Belgium, 2012.

[3] J. A. Vega and C. A. Hidalgo, “Quantitative risk assessment of landslides triggered by earthquakes and rainfall based on direct costs of urban buildings,” *Geomorphology*, vol. 273, pp. 217–235, 2016.

[4] M. GhafouriAshtiani, *Seismic Risk Reduction in Tehran*, National Committee to Reduce the Effects of Natural Disasters, Tehran, Iran, in Persian, 2001.

[5] S. Yasuda and T. Hashimoto, “New project to prevent liquefaction-induced damage in a wide existing residential area by lowering the ground water table,” *Soil Dynamics and Earthquake Engineering*, vol. 91, pp. 246–259, 2016.

[6] S. A. Hosseini and H. H. Machyani, “Locating sites for temporary accommodation and food storage silos in the event of a crisis in rasht city-Iran,” *J. Mater. Environ. Sci*, vol. 6, no. 10, pp. 2825–2835, 2015.

[7] M. Esmaelian, M. Tavana, F. J. S. Arteaga, and S. Mohammadi, “A multicriteria spatial decision support system for solving emergency service station location problems,” *International JournalOf Geographical Information Science*, vol. 29, no. 7, pp. 1187–1213, 2015.

[8] J. M. Marcelin, M. W. Horner, and E. E. Ozguven, “How does accessibility to post disaster relief compare between the aging and the generalpopulation? A spatial network optimization analysis of hurricane relief facility locations,” *International Journal of Disaster Risk Reduction*, vol. 15, pp. 61–72, 2016.

[9] W. Chen, G. Zhai, C. Fan, W. Jin, and Y. Xie, “A planning framework based on system theory and GIS for urban emergency shelter system: a case of Guangzhou, China,” *Human and Ecological Risk Assessment: An International Journal*, vol. 23, no. 3, pp. 441–456, 2017.

[10] B. Saeidian, M. S. Mesgari, B. Pradhan, and M. Ghodousi, “Optimized location-allocation of earthquake relief centers using PSO and ACO, complemented by GIS, clustering, and TOPSIS,” *ISPRS International Journal of Geo-Information*, vol. 7, no. 8, p. 292, 2018.

[11] M. M. L. Nappi, V. Nappi, and J. C. Souza, “Multi-criteria decision model for the selection and location of temporary shelters in disaster management,” *Journal of International Humanitarian Action*, vol. 4, no. 1, p. 16, 2019.

[12] H. Baharmand, T. Comes, and M. Lauras, “Supporting group decision makers to locate temporary relief distribution centres after sudden-onset disasters: a case study of the 2015 Nepal earthquake,” *International Journal of Disaster Risk Reduction*, vol. 45, Article ID 101455, 2020.

[13] K. Borhani, A. AzimzadehIrany, and A. Elhami, “Spatial analysis of urban multi-functional land uses integrating MCDM and GIS methods Case study: emergency shelter in Saravan City,” *Scientific-Research Quarterly of Geographical Data (SEPEHR)*, vol. 29, no. 116, pp. 103–118, 2021.

[14] H. Su, W. Chen, and M. Cheng, “Using the variable two-step floating catchment area method to measure the potential spatial accessibility of urban emergency shelters,” *GeoJournal*, pp. 1–15, 2021.

[15] Y. Yao, Y. Zhang, T. Yao, K. Wong, J. Y. Tsou, and Y. Zhang, “A GIS-based system for spatial-temporal availability evaluation of the open spaces used as emergency shelters: the case of Victoria, British Columbia, Canada,” *ISPRS International Journal of Geo-Information*, vol. 10, no. 2, p. 63, 2021.

[16] R. M. Gray, *Entropy and Information Theory*, Springer Science & Business Media, Berlin, Germany, 2011.

[17] W. K. Brauers and E. K. Zavadskas, “The MOORA method and its application to privatization in a transition economy,” *Control and Cybernetics*, vol. 35, pp. 445–469, 2006.

[18] A. Azar and A. Rajabzadeh, “Applied decision making of MADM approach, tehran,” 2010.

[19] P. Ghasemi and E. TalebiBrijani, “An integrated FAHP-PROMETHEE approach for selecting the best Flexible manufacturing system,” *European Online Journal of Natural and Social Sciences*, vol. 3, no. 4, p. 1137, 2014.

[20] S. Mamalis, I. Kamenidou, S. Pavlidis, and A. Xatziaggelou, “Perceptions of hospital quality: a case study from Greece,” in *Strategic Innovative Marketing and Tourism*, pp. 403–410, Springer, Cham, Switzerland, 2020.

[21] M. Behzadian, R. B. Kazemzadeh, A. Albadvi, and M. Aghdasi, “PROMETHEE: a comprehensive literature review on methodologies and applications,” *European Journal of Operational Research*, vol. 200, no. 1, pp. 198–215, 2010.

[22] S. Greco, J. Figueira, and M. Ehrgott, *Multiple Criteria Decision Analysis*, Springer, New York, NY, USA, 2016.

[23] X. Qi, X. Yu, L. Wang, X. Liao, and S. Zhang, “PROMETHEE for prioritized criteria,” in *Soft Computing*vol. 23, no. 22, pp. 11419–11432, 2019.

[24] P. Verma, “Promethee: a tool for multi-criteria decision analysis,” in *Multi-Criteria Decision Analysis in Management*, pp. 282–309, IGI Global, Hershey, PA, USA, 2020.

[25] Habibi, M. Seyed, and M. Sedigheh, *Per Capita Urban Land Use*, National Land and Housing Organization Publications, Tehran, Iran, 1999.

[26] L. Zhao, H. Li, Y. Sun et al., “Planning emergency shelters forUrban disaster resilience: an integrated location-allocation modeling approach,” *Sustainability*, vol. 9, no. 11, p. 2098, 2017.

[27] C. Jica, “The study on seismic microzoning of the Greater Tehran Area in the Islamic Republic of Iran,” Pacific Consultants International Report, OYO Cooperation, Tokyo, Japan, 2000.

[28] A. Baležentis, T. Baležentis, and W. Brauers, “MULTIMOORA-FG: a multi-objective decision making method for linguistic reasoning with an application to personnel selection,” *Informatica*, vol. 23, no. 2, pp. 173–190, 2012.

[29] T. Balezentis and A. Balezentis, “A survey on development and applications of the multicriteria decision making MethodMULTIMOORA,” *Journal of Multi-Criteria Decision Analysis*, vol. 21, pp. 209–222, 2014.

[30] F. Jolai, M. J. Rezaee, and A. Vazifeh, “Multi-criteria decision making for assembly line balancing,” *Journal of Intelligent Manufacturing*, vol. 20, no. 1, pp. 113–121, 2009.

[31] M. J. Rezaee and S. Yousefi, “An intelligent decision making approach for identifying and analyzing airport risks,” *Journal of Air Transport Management*, vol. 68, pp. 14–27, 2018.