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Amir Reza Bakhshi Lomer [1], Mahdi Rezaeian [2], Hamid Rezaei [3], Akbar Lorestani [4], Naeim Mijani [5,*], Mohammadreza Mahdad [6], Ahmad Raeisi [7] and Jamal Jokar Arsanjani [8]

1 Department of Geography, Birkbeck University of London, London WC1E 7HX, UK
2 Department of Geographic Information System Engineering, College of Engineering, University of Tehran, Tehran 1439957131, Iran
3 Department of Civil and Environmental Engineering, Florida International University, Miami, FL 33174, USA
4 Faculty of Geography, University of Tehran, Tehran 1417935840, Iran
5 Department of Remote Sensing and GIS, University of Tehran, Tehran 1417853933, Iran
6 Detailed Planning of Urban Development Vice-Chancellor, Isfahan 1st District Municipality, Isfahan 8145913151, Iran
7 Department of Electrical and Computer Engineering, University of Tehran, Tehran 1439957131, Iran
8 Geoinformatics Research Group, Department of Planning and Development, Aalborg University Copenhagen, DK-2450 Copenhagen, Denmark
* Correspondence: naeim.mijani@ut.ac.ir

Abstract: This study presents a novel risk-based decision support system for helping disaster risk management planners select the best locations for emergency shelters after an earthquake. The system starts by identifying 18 criteria, based on stakeholder analysis, that are important for selecting shelter sites. These criteria are then standardized to reflect their importance in the site selection process. Next, a Large Group Decision-Making (LGDM) model is used to determine the weight of each criterion based on collective intelligence. Finally, the Ordered Weighted Average (OWA) method is used to assess the suitability of different geographical locations for emergency shelters, resulting in a suitability map. The factors that were most significant for selecting the best emergency shelters were the distance from the fault, population density, access to green spaces, and building quality. The area of the optimal sites for emergency shelters in the region varied depending on the decision-maker's risk attitude, ranging from 4% in an extremely pessimistic scenario to 28% in an extremely optimistic scenario. This system combines Geographic Information Systems (GIS) and LGDM to help decision-makers identify the optimal sites for emergency shelters under different risk levels, which can contribute to better-informed decision-making regarding disaster resilience.

Keywords: earthquake; emergency shelter; site selection; Large Group Decision-Making (LGDM)

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1. Introduction

The occurrence of disasters, whether natural or man-made, is an inevitable part of all societies. However, depending upon the type and extent of the disaster, as well as its location, it may have a variety of negative consequences [1,2]. One of the natural phenomena the neglect of which will cause irreparable damage to society is earthquakes [3,4]. Cities are more vulnerable to natural disasters such as earthquakes due to population density and economic activities in large and dense areas [5,6].

A major problem that wastes a great deal of time and energy for managers during a crisis is the provision of appropriate emergency shelters for those who have been evacuated. It is necessary to evacuate people as fast as possible during earthquakes since many human and financial losses occur as a result of the main earthquake, as well as the risks of secondary disasters [7,8]. Hence, it is critical that sites for the emergency housing of people who have lost their shelter as a result of the earthquake disaster be identified [9,10]. This can contribute to improving the ability of local governments to deal with disasters and ensure public safety [11].

In relation to disaster shelters, requirements differ depending on the duration of the disaster, and they are different from other buildings or structures [12]. There are four stages in the post-earthquake recovery process: immediate relief (hours), emergency sheltering (days), temporary accommodation (weeks), and permanent accommodation (months) [13]. During the emergency shelter period, areas under the direct control of local governments and regional authorities can easily be used as shelters, in contrast to private lands [14]. It is important to ensure that an acceptable shelter meets the safety standards needed to prevent disasters and their consequences. These features include high accessibility, making it possible for evacuated individuals to access the site, as well as the ability to accommodate a large number of individuals [15].

Most people affected by disasters prefer to remain near their damaged homes and their belongings [16,17]. However, after the main earthquake, there is a possibility that aftershocks or secondary disasters will occur. The most effective form of emergency and temporary accommodation is to prepare local shelters in parks, open spaces, and earthquake-proof buildings within the city and around it [5,18–20]. Educational, cultural, and sport centers that are sufficiently spacious and earthquake-resistant are considered safe public buildings. It has been suggested that these sites may also be suitable for accommodating evacuated people following earthquakes and supporting their primary concerns [10]. In order to come up with an optimal site selection, a lot of detailed information needs to be collected, combined, and analyzed. Desirable site selection is achieved when the degree of desirability of different locations is accurately, homogeneously, and quickly evaluated [21,22].

For the selection of optimal emergency shelter sites, it has been demonstrated in previous studies that integrating Multi-Criteria Decision-Making (MCDM) with Geographic Information Systems (GIS) is beneficial. The GIS-MCDA method combines spatial data (criterion maps) with values derived from decision-makers' judgments to provide useful information for spatial decision-making. Among the key advantages of GIS-MCDA methods is that these two techniques can work together as complementary tools. GIS can store, manipulate, analyze, and visualize geospatial information in creative ways. However, multi-criteria decision making provides a set of methods for analyzing, evaluating, and prioritizing options that can be used to solve decision-making problems [23–26]. It is relevant to note that criteria selection may vary, but generally include safety (distance from hazardous facilities), accessibility (road network, distance from critical facilities), and operational efficiency (capacity, area) [27–29]. According to Xu, et al. [30], a multi-criteria constraint location method with GIS support was developed to solve the problem of shelter site selection from the perspective of urban planning. Li, et al. [31] utilized a hierarchical model combined with GIS to select emergency shelters after disasters in Shanghai, China. Trivedi [32] assessed and prioritized different aspects of shelter location. The findings indicated that terrain, transportation infrastructure, community, and type of ownership all play significant roles in determining the location of emergency shelters. In order to obtain optimal emergency shelters as a critical component of disaster management, Shi, et al. [33] developed a model based on the weighted Voronoi diagram and GIS. In order to determine the optimal location of emergency shelters in small mountain cities, they developed multi-level location methods for different levels of emergency shelters with the goal of minimizing travel and construction budgets while maximizing coverage. Hosseini, et al. [34] presented a multi-criteria decision-making approach that utilizes a knapsack algorithm and an integrated value model for sustainability assessment in Tehran, Iran, to assist decision-makers in selecting optimal site locations by assessing a variety of alternatives. Tsioulou, Faure Walker, Lo and Yore [27] presented a method for evaluating the relative suitability of various school buildings as emergency shelters based on the AHP. Based on the aggregated weights, it is evident that hard (hazards and physical vulnerability) and soft (access to supplies, and accessibility) factors should be given relatively equal importance.

As well, some studies have been conducted on optimization models aimed at improving the functionality of emergency shelters. For example, Hu, et al. [35] have developed an integrated optimization model for improving shelter efficiency. This model emphasizes the boundaries of service areas and evacuation routes, as well as minimizing the length of evacuation paths from a given population to an assigned shelter using a ripple-spreading algorithm. Kocatepe, et al. [36] proposed an optimization model based on spatially capacitated p-medians for the selection of shelter locations in south Florida for evacuated people with special conditions or pets. Ma, et al. [37] developed a model using a multi-objective mathematical method combined with a modified particle swarm optimization (PSO) algorithm to select suitable shelters among various alternatives and allocate populations to them. Furthermore, a multi-objective optimization approach for emergency evacuation planning was presented by Dulebenets, et al. [38], which considered social and engineering aspects, and minimized the total evacuation time. Implementing the proposed approach was expected to enhance safety and ensure timely evacuation from disaster zones.

Considering our knowledge derived from previous studies, Large Group Decision-Making (LGDM) models and collective intelligence approaches have not been used to select emergency shelters. LGDM models are among the new GIS-MCDM models whose use is growing in most spatial studies. These models do not have the limitations of common and traditional weighting methods, such as uncertainty and inconsistency in the opinions of a small number of experts. Additionally, in this study, for the first time, the impact of different attitudes of managers and planners on determining the optimal sites for emergency shelters, including extremely optimistic, optimistic, neutral, pessimistic, and extremely pessimistic decision-making attitudes, has been taken into account. These attitudes can be directly related to the amount of budget available to the manager for the preparation of emergency shelters. If there are no financial restrictions, the results of optimistic attitudes (risk-taking decision-making) can be used. In the case of financial constraints, the results of pessimistic attitudes (risk-averse decision-making) can be used. Hence, the aim of this study is to provide a novel risk-based support system for decision-making by managers and experts to determine the optimal sites for emergency shelters. In contrast to the previous study, this study makes use of (1) Large Group Decision-Making based on a collective intelligence approach to determine the weights of effective criteria, and (2) the Ordered Weighted Average (OWA) method for selecting optimal sites for emergency shelter based on different degrees of risk in the decision-making process.

2. Study Area

The study area includes District 1 of the Isfahan metropolis in Iran (Figure 1). This area is one of the busiest of the 15 districts of Isfahan Municipality and its area is about 810 ha. This area has a population of about 79,091, and its 5-year growth rate is 0.3%. The density in this area is 97.6 people per hectare. The total green space in this area is 549,486 m^2, which is the lowest amount after District 11 of the Isfahan metropolis. This area also has four main parks, 12 local parks and seven neighborhood parks. Additionally, this area has three indoor sports complexes, three libraries and study halls, and three socio-cultural centers. The number of public parking lots in this area is 17 with an area of 79,790 m^2 and a capacity of 2647 cars. This area has 11 neighborhoods. These neighborhoods are different in terms of sustainable neighborhood indicators, and also have significant differences from each other in terms of population and area. There are several planned use classes in District 1, including residential, commercial, warehouses, and small workshops. There are five areas of old and worn-out textures in District 1. The total area of worn-out textures in District 1 is equal to 2,390,000 m^2, which includes a significant part of this district. The characteristics of the selected district for the present study are shown in Figure 1.

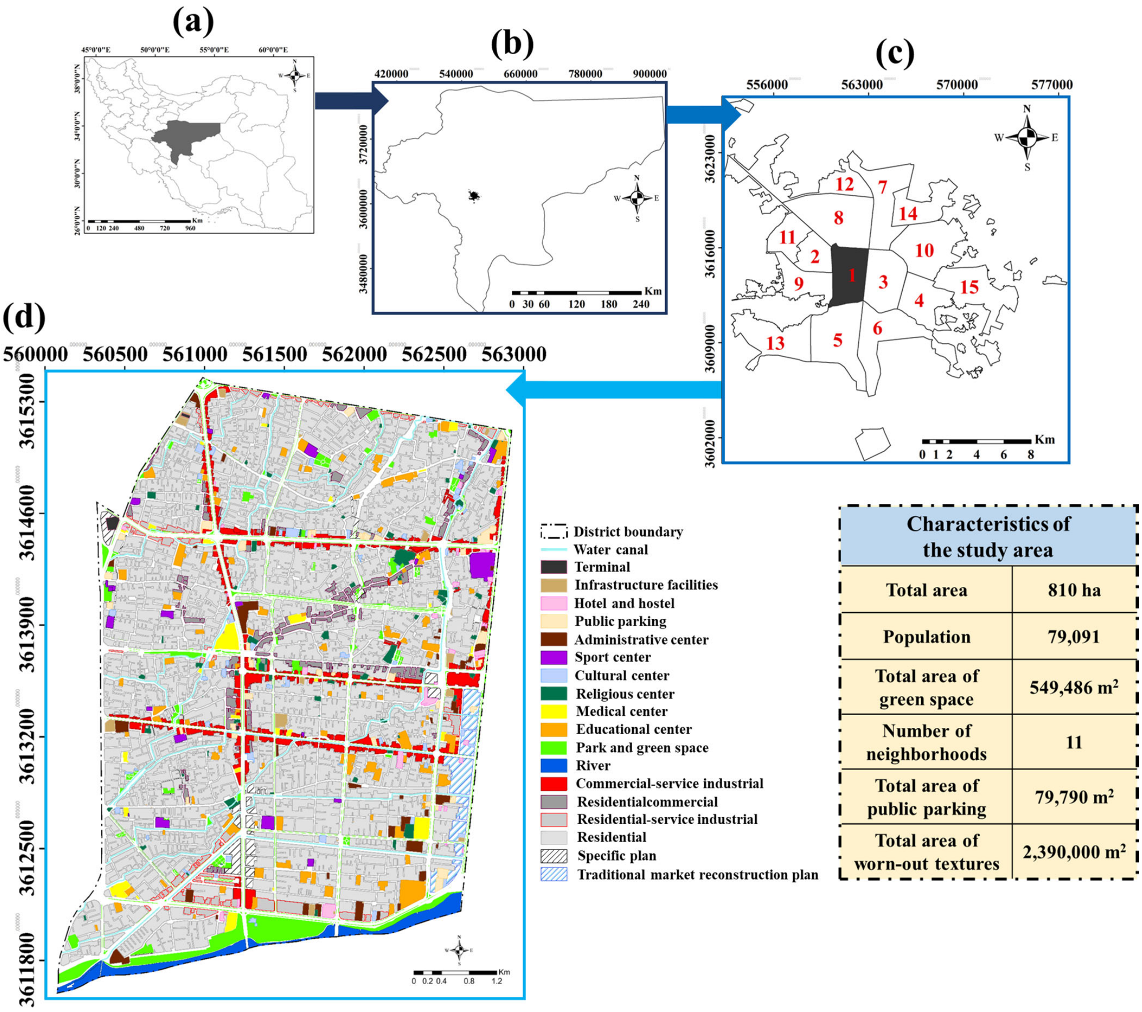

Figure 1. Location of the study area: (**a**) Isfahan province location in Iran, (**b**) location of Isfahan city in Isfahan province, (**c**) location of District 1 in Isfahan city, (**d**) geographical location of District 1 along with its main streets.

3. Materials and Methods

3.1. Data

There are two main types of data and information required for this research. These are spatial data that were collected by creating a database in a GIS environment and descriptive and statistical information that was collected from related organizations. The data used in this study are as follows:

- 1/50,000 map of fault location in DGN format, Iran National Cartographic Center;
- 1/25,000 topographic map in DGN format, Iran National Cartographic Center;
- Map of infrastructure facilities (electricity power lines and stations, main gas lines) in DGN format, National Iranian Gas Company and Electricity Distribution Company in Isfahan city;
- Map of land use and ownership types in DGN format, Isfahan District 1 Municipality;
- Quality map of buildings;
- Map of urban metro lines in DGN format, Urban Transport Organization;
- Road network map (major and minor arterial roads) in DGN format, Isfahan District 1 Municipality;
- Demographic information by building blocks, Statistical Centre of Iran;
- Map of worn-out textures in DGN format, Isfahan District 1 Municipality;
- Map of service centers (police station, medical center, fire station, and educational center) in DGN format, Isfahan District 1 Municipality;

- Worldview satellite image of District 1.

3.2. Methods

In this study, we selected optimal post-earthquake emergency shelter sites using collective intelligence in the field of group decision-making. We used multi-criteria spatial decision-making analysis along with different degrees of risk. The main steps of the study are shown in Figure 2. In the first step, according to the review of previous studies and the opinions of various experts, effective criteria were selected from among the primary criteria. Using the set of GIS spatial analysis tools, information layers have been prepared in the form of criteria maps for the selected criteria. Then, all criteria layers were standardized using the standardization method in order to equalize and integrate the standard layers. We have standardized the criteria based on the type and nature of their effect on the selection process. In the second step, based on the LGDM model and the opinions of different groups of experts, the weight (importance degree) of each criterion layer has been calculated. Due to this, specialized groups have been formed from various experts related to the study problem, each with equal numbers. Experts weigh the criteria based on a pre-established set of identifiers. In the third step, using the OWA method, standardized criteria layers are combined with each other according to the weights (obtained from the second step) in different degrees of risk. In the final step, post-earthquake emergency shelters in various risk levels have been identified on desirability maps.

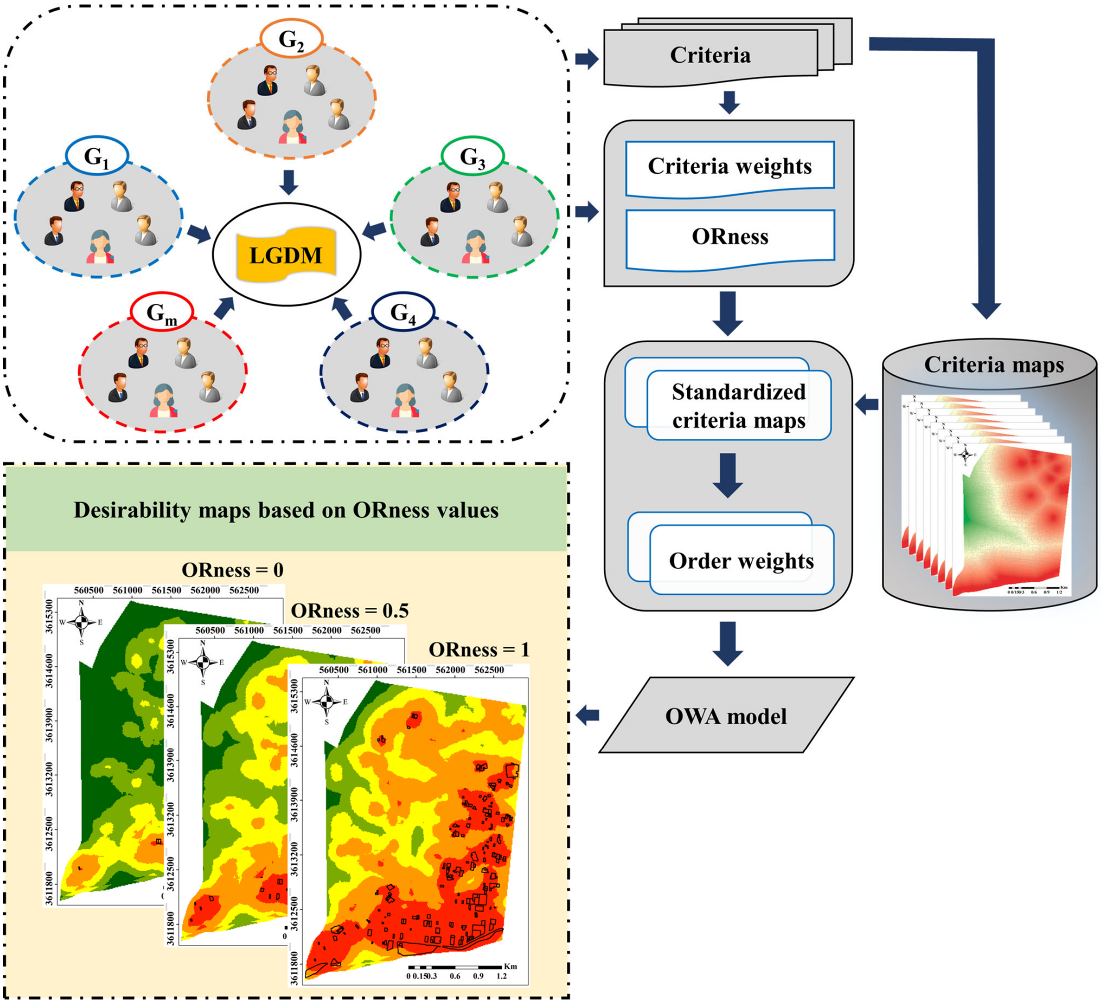

Figure 2. Study methodological flowchart.

3.2.1. Effective Criteria

In this study, according to the characteristics of the case study and the expert opinions of different groups, 18 effective criteria, including population density, distance from fault, building quality and material, high-rise buildings, worn-out textures, metro lines, hazardous facilities (fuel or chemical storage sites and gas stations), as well as access to major, minor arterial roads and local roads, medical centers and hospitals, police stations, educational centers, sports centers, cultural centers (administrative and religious), fire stations, open spaces, and parks, were considered to select optimal sites for emergency shelter. It is worth mentioning that the distance layers from different criteria were converted into raster maps by applying the Euclidean distance function. Afterward, they were standardized between 0 and 1 using one of the minimum or maximum methods. The descriptions of the criteria are given as follows in Table 1.

Land uses that are within each other's sphere of influence should, from the point of view of urban planning, be compatible in terms of their activities. They should not interfere with each other. Therefore, every urban land use has incompatibility with some uses and compatibility with others, and this compatibility and incompatibility is determined by factors such as possible risks, access, etc. [39]. On the topic of emergency shelter selection, urban land uses can be divided into two main compatible and incompatible categories. In the site selection process, the intended land use must be in the area of influence of compatible land uses. Shelters must be located in close proximity to compatible facilities and land uses in order to strengthen their functions. After an earthquake, compatible land uses reduce the damage caused by the event. These land uses include open and green spaces, fire stations, medical and health centers, educational centers, sports centers, police stations, and critical facilities. Furthermore, the distance of emergency shelters from incompatible land uses is one of the most decisive determining factors in site selection, so as to reduce the severity of vulnerability. Incompatible land uses include gasoline and gas stations, high-voltage transmission lines, water canals, hazardous facilities, worn-out textures, and high-rise buildings [40–42].

Table 1. Description of various spatial criteria used in this study.

Criteria	Description
Distance from faults	Buildings under high risk of fault are more likely to collapse [43]. For the preparation of the standard fault layer, 63 important active faults were selected. The fault's location was extracted based on a 1/50,000 map of the Iran National Cartographic Center. As regards emergency shelter selection, more distance from faults is more desirable.
Population density	In high-density areas of a city, the probability of damage and losses caused by a disaster is greater than in low-density areas. In other words, as far as possible, it is better to select emergency shelters in low-density areas so that they are less vulnerable to damage when earthquakes occur [5,44]. In order to prepare the standard population density layer, demographic information was prepared by block and neighborhood in the shapefile format from the Statistical Centre of Iran. The population density was calculated using the area of each block and neighborhood. Finally, the standard population density layer was converted into raster format and standardized.
Access to the transport network (including distance from metro lines, distance from minor arterial roads, and distance from major arterial roads)	A condition of accessibility includes criteria relating to road accessibility and the response speed of rescue services [45,46]. The emergency shelter site should be next to or near the roads that provide access to various centers. The possibility of vulnerability and blockage of these roads should be low to reduce the risks associated with stopping operations such as emergency evacuation and accommodation [47]. Considering the possibility of falling and fires on metro lines after an earthquake, the greater the distance, the more desirable the site of an emergency shelter. The DGN file prepared by the Urban Transport Organization was used to prepare the distance layers from major and minor arterial roads and metro lines. In terms of emergency shelter selection, less distance from major and minor arterial roads is more desirable.

Table 1. *Cont.*

Criteria	Description
Distance from medical centers	One of the main criteria for selecting optimal sites for emergency shelters is proximity to medical centers and hospitals. During the time following an earthquake, proximity to these centers allows victims to be transferred to these centers quickly and save lives [48,49].
Distance from fire stations	Another critical service in cities is the fire department. The location of fire stations is one of the most effective criteria for selecting optimal sites for emergency shelters. Less distance and easy access increase the efficiency of fire station services to emergency shelters [15].
Distance from police station	The proximity of emergency shelters to police stations can greatly help to increase the victims' sense of security and peace, as well as make it easier for the police to establish security [32].
Distance from open spaces and parks	Access to parks and open spaces is always considered one of the available options for the establishment of emergency shelters. To check this criterion, the distance of access is considered. As a result, the less distance to parks and open spaces, the more desirable it is [34].
Distance from educational centers	Education centers (schools, conservatories, and universities) that meet earthquake resistance standards can also serve as emergency shelters. Due to the presence of many open spaces, basic facilities and various buildings, educational centers have a high potential for post-earthquake emergency accommodation of victims.
Distance from cultural centers	Newly built and standard administrative and cultural centers are among other important compatible land uses in the area of emergency shelter selection. Generally, administrative and cultural buildings are more resistant to earthquakes than residential buildings. Also, in crisis situations, administrative centers act as disaster management command centers. On the topic of emergency shelter selection, less distance from educational, cultural, and administrative centers is more desirable.
Distance from hazardous facilities	After earthquakes, a key factor that aggravates damages and casualties is hazardous facilities. These facilities include gas stations, fuel and chemical storage sites, high-voltage transmission lines, pressure booster stations, etc. It is always necessary to stay away from these facilities when selecting the optimal sites for emergency shelters on a regional scale [50].
Distance from high-rise buildings	High-rise buildings are another building type that is incompatible with disaster risk management. Increasing the number of floors in buildings will cause more damage. It will be difficult to evacuate and shelter during a crisis. The farther away the emergency shelter is from high-rise buildings, the more desirable the site is [15].
Distance from water canals	An irrigation canal is an artificial waterway with a gentle slope that transports water entering a city from its main course to other sections [51]. As part of the topic of post-earthquake emergency shelter selection, it is necessary to take into account the location of water canals because the materials that make up canals are not very strong, and a possible fall during the earthquake would cause the network of roads to be disrupted. Therefore, it is more desirable to have more distance between emergency shelter sites and water canals.
Distance from sports centers	As a precautionary measure during natural disasters, public open spaces are often considered as optimal sites for emergency shelters. This is particularly the case for sports centers, which are commonly used as evacuation hubs after seismic events.
Distance from worn-out textures	Worn-out textures are vulnerable due to physical deterioration and appropriate inaccessibility, as well as a lack of urban facilities and infrastructures. Therefore, the further the emergency shelter is from worn-out textures, the higher its spatial value.
Distance from petrol stations	People need to avoid high-risk places, such as places prone to fires, particularly petrol stations. Thus, the further the distance from petrol station, the more desirable it is for emergency shelter selection.
Building quality	Buildings are the most important and main elements that are damaged when an earthquake occurs. The resistance of buildings and building materials is not the same in various areas. The use of resistant building materials and compliance with standards in construction reduce vulnerability to earthquakes.

3.2.2. Standardization of Criteria

The current study presents each criterion as a map layer that is dimensionless and has been standardized by a linear scale transformation method based on the highest and lowest values of each criterion. Equations (1) and (2) can be utilized, respectively, to convert criterion maps (values) into standardized maps, based on whether the criterion is to be maximized (i.e., a higher value indicates more desirability) or minimized (i.e., a lower value indicates more desirability) [52]. For emergency shelter selection, Equation (1) is used to standardize criteria whose highest and maximum values are more desirable, and Equation (2) is used to standardize criteria whose lowest and minimum values are more desirable.

$$x_{ij} = \frac{X_{ij} - X_j^{min}}{X_j^{max} - X_j^{min}} \tag{1}$$

$$z_{ij} = \frac{Z_j^{max} - Z_{ij}}{Z_j^{max} - Z_j^{min}} \tag{2}$$

where x_{ij} and z_{ij} represents the standardized values of maximized and minimized criterion, respectively. Furthermore, X_{ij} and Z_{ij} are the values of the ith position for the jth criterion, X_j^{min} and Z_j^{min} are the lowest values, and X_j^{max} and Z_j^{max} are the highest values of the jth criterion.

3.2.3. Criteria Weighting Based on LGDM

Large Group Decision-Making (LGDM) refers to determining the best option from a set of available options based on the opinions of a large number of people. Due to the fact that decisions may have consequences for many individuals, it is necessary to involve a large number of individuals from a variety of interest groups in the decision-making process [53,54]. The LGDM method involves participants from several groups with varied specialties, making it a special type of group decision-making (GDM) method. Traditional GDM methods involve fewer participants. In LGDM, participants are spread across multiple groups, and decision-relevant information is provided by the participants in large quantities, which leads to outcomes that are independent of individual tendencies [55,56].

This study used the LGDM method proposed by Liu, Fan and Zhang [56] for criteria weighting. Liu, Fan and Zhang [56] presented an LGDM method that integrates information provided by experts from multiple groups to make a decision. In this LGDM method based on the collective intelligence approach, an acceptable number of experts from different groups participate in the decision-making process and express their personal opinions for the predetermined. Since percentage distributions describe the opinions of each group regarding each criterion, the percentage distributions of those opinions are calculated and analyzed. In the following, the level of consensus of each group on each criterion is calculated. If there is an acceptable consensus in the group, the objective weight of each criterion in that group is calculated. This weight is calculated based on the opinions of the majority of experts. Then, the objective weight of each group for each criterion is aggregated with the subjective weight of that group assigned by the researchers. In other words, the final weight of the criterion in each group is determined by summing the objective weight and the subjective weight. After that, the collective percentage distributions related to each criterion are calculated by combining the final weight of the criterion and the percentage distributions of all groups. In other words, by combining the percentage distribution and the final weight of each criterion in different groups, the collective weight of the criterion is calculated and determined. This method implicitly introduces the concept of optimal majority in the prioritization of decision-makers in the group decision-making process. More details of this method can be found in Liu, Fan and Zhang [56].

Figure 3 shows the steps of calculating the weight of criteria based on LGDM. The descriptions of the related sets and variables used in Figure 3 are as follows:

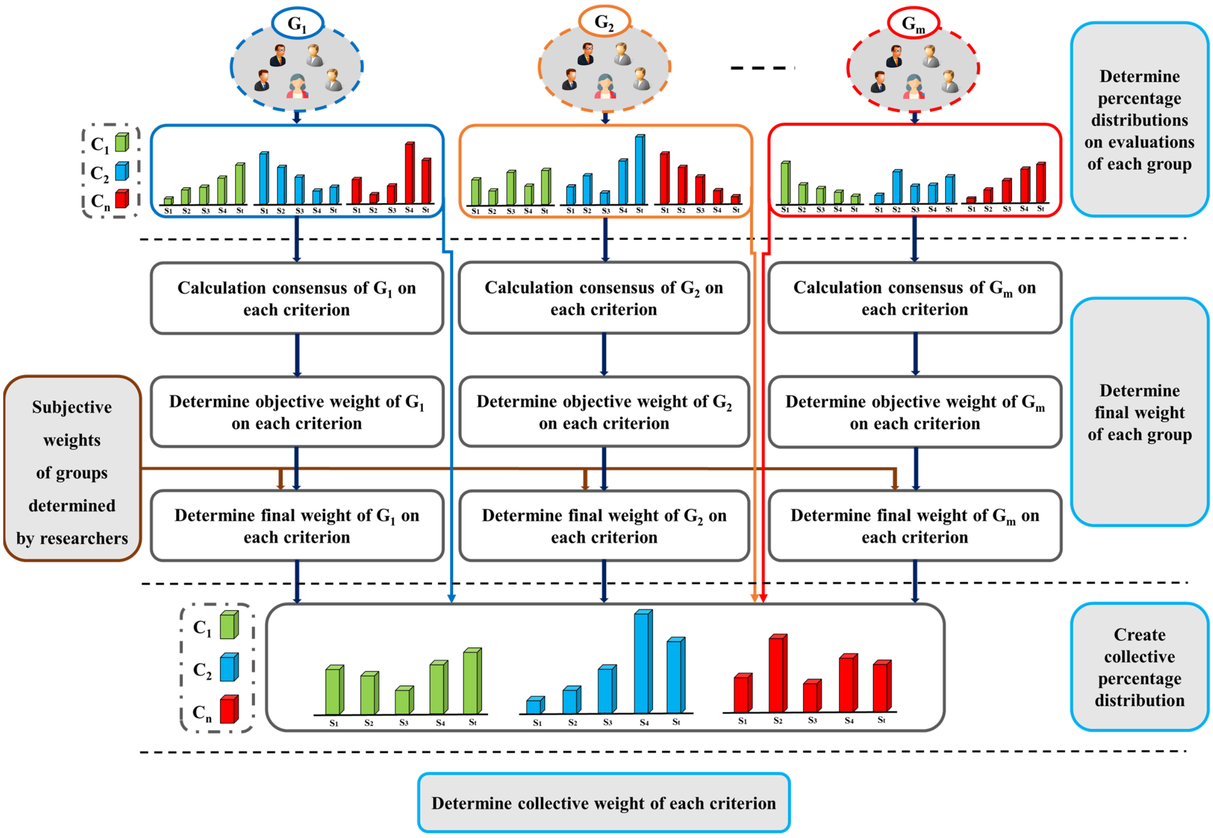

Figure 3. An overview of the LGDM method used in this study for criteria weighting.

- $C_1, C_2, \ldots, C_n$—the set of effective criteria, so that C_i represents the *i*th criterion ($i = 1, 2, \ldots n$);
- $G_1, G_2, \ldots, G_m$—the set of m groups with different expertise, so that G_j represents the *j*th group that participates in the decision-making process ($j = 1, 2, \ldots m$);
- $S_1, S_2, \ldots, S_t$—the set of t evaluation identifiers, so that S_p represents the *p*th evaluation identifier. The evaluation identifiers are used to rank the criteria in terms of importance by each expert ($St > \cdots > S2 > S1$). After standardizing the criteria, according to the varying impacts of each criterion on determining emergency shelter sites, the criteria are weighted using the LGDM method.

In the present study, the participants in the LGDM approach included academic experts and executive agencies. The number of these people in the first step was 1200, and in the next step, a limited number of these people were selected based on the specific indicators to determine criteria weight based on the LGDM approach. The selection indicators for these experts were having undertaken distinguished scientific, research, and executive activities in the field of temporary accommodation and crisis management. Academic experts consist of university professors, postdoctoral researchers, and philosophy doctoral students with distinguished scientific and research activities in this field. Moreover, the experts of executive agencies include experts and consultants of technical departments of related agencies with implementation experience who have completing successful projects in the field of temporary accommodation and crisis management.

Five expert groups with different types of specialized knowledge in total were used to determine the weight of the criteria in the site selection issue. Considering the collective intelligence approach of the research and the limited number of experts in the selected district, the opinions of other experts in Isfahan city and the country were also used. The total number of selected experts was 398. For the final weight of the criteria, the relative importance (subjective weight) of the opinions of each group differs depending on the study objectives and previous studies. In Table 2, the specialty, number, and relative importance of each group involved in decision-making are mentioned.

Table 2. Specialty, number, and relative importance (subjective weight) of each group involved in decision-making.

Group	Specialty	Number	Weight
1	Disaster management/Rescue management/Environmental hazards management	78	0.30
2	Urban planning/Urban management/Urban engineering	85	0.23
3	Geology/Geomorphology/Seismology	79	0.20
4	Civil engineering (Infrastructure/Structural/Geotechnical/Transportation)	76	0.17
5	Geographic Information Science (GIS)	80	0.10

3.2.4. OWA Method

The decision-making process in many site selection issues is affected by a risk environment owing to a lack of accurate predictions of future events, a lack of access to accurate and definitive information, and a lack of accurate evaluation of some criteria, especially qualitative criteria. People who are risk-takers emphasize the positive characteristics of an option (criterion), whereas people who are risk-averse emphasize the negative characteristics of an option (criterion) and use it as a basis for choosing. It is important to note that decision-makers' levels of risk-taking and risk-aversion impact the final answer in this environment. As one of the ordered decision-making methods capable of taking into account the priorities and evaluations of decision-makers, the ordered weighted average (OWA) method is introduced. A method such as the OWA can be used to determine the level of risk-taking and risk-aversion of a decision-maker and input that information into selecting the final option [24,57].

Yager [58] proposed the OWA as one of the multi-criteria aggregation methods. Over the past few years, the OWA method has been widely used in a broad range of spatial decision-making and assessment applications, including land-use suitability analysis [59], vulnerability assessment of earthquake hazards [60] and multi-criteria site selection for various applications [61–64]. As a result of its ability to select different sets of order weights, the OWA method has the capability of implementing a wide range of combination operators.

In the OWA model, ORness is used as a parameter regulating the degree of decision risk. As a result of the order weights, the level of risk (or ORness degree) is implicitly controlled. Decision-makers can use the ORness parameter to guide them along a continuum of decision-making conditions, ranging from extremely pessimistic to extremely optimistic. ORness values range from 0 to 1. The heightened and lower ORness values emphasize the higher (better) values and the lower (worse) values in a set of criteria [52,61,65]. The details of the OWA implementation are provided in Yager [58].

Compared to other ORness values, ORness = 0 (i.e., risk averse or pessimistic) indicates the most optimal locations for emergency shelters (a highly desirable class), which have the lowest area. It should be pointed out that this decision-making attitude (ORness = 0) is used when the sensitivity is very high to determine optimal sites, and there are specific economic restrictions for allocating resources. As the value of ORness increases, risk-taking in decision-making also increases. As such, ORness = 1 (i.e., risk-taking or optimistic) indicates the highest area of optimal locations for emergency shelters (a highly desirable class) compared to other ORness values. As a result, a more significant portion of the district is selected as highly desirable. This decision-making attitude (ORness = 1) is used when there is neither high sensitivity to determining optimal sites nor restrictions on the allocation of resources to equip emergency shelters. In the present study, the OWA method was implemented under five different decision-making conditions in terms of the degree of risk. ORness values ranging from 0 to 1 indicate extremely pessimistic (ORness = 0), pessimistic (ORness = 0.25), neutral or moderate (ORness = 0.5), optimistic (ORness = 0.75) and extremely optimistic (ORness = 1) decision-making conditions. Additionally, the desirability maps of emergency shelter sites obtained from the OWA method are divided into five classes: highly undesirable (0–0.2), undesirable (0.2–0.4), moderate (0.4–0.6), desirable (0.6–0.8), and highly desirable (0.8–1). In District 1 of Isfahan city, 36 ha were required for post-earthquake emergency sheltering for 79,091 people based on previous studies and international standards.

4. Results and Discussion

The standardized criteria maps used in selecting optimal sites for post-earthquake emergency shelter in District 1 of Isfahan city are shown in Figure 4. Standardized criteria were mapped in the range of 0 to 1, with values close to 1 (red) indicating higher desirability in terms of emergency shelter selection, whereas values close to 0 (green) indicate lower desirability.

The weights calculated from the LGDM method are shown in Figure 5. The more weight a criterion has, the more effective it is in the site selection process compared to other criteria. The results show that there is a high consistency between the experts' opinions in determining the priority and weight of the criteria. Based on the results of the LGDM method, the criterion of distance from the fault with a weight of 12% and the criterion of distance from the metro lines with a weight of 1.7% have the highest and lowest relative importance values in the site selection process, respectively. Among other criteria, population density with a weight of 11.5% and access to open spaces and parks with a weight of 9.5% are also very important. Additionally, among other less important criteria in this study, we can refer to the criterion of distance from water canals, with a weight of 1.9%, and the criterion of high-rise buildings, with a weight of 2.2%.

Managers and urban planners make decisions based on different levels of risk. Some have a risk-taking attitude, others have a neutral attitude (intermediate conditions), while others have a risk-averse attitude [57]. Risk-averse managers and planners mostly look for locations to allocate credit where all the effective criteria are as good as possible in projects and plans related to the establishment, development, and equipping of emergency shelter sites. In fact, managers in these locations will more likely achieve the desired and predicted efficiency. This is because the criteria are more comprehensive in these locations, and they have the best possible conditions. The risk-averse attitude is very helpful when relevant organizations have limited financial resources. The desirability maps for emergency shelters and the optimum locations in the highly desirable classes based on different ORness values are shown in Figure 6.

Under extremely pessimistic decision-making conditions (ORness = 0), the areas of highly desirable, desirable, moderate, undesirable, and highly undesirable classes are 30.48, 63.28, 176.1, 290.76, and 253.6 ha, respectively. The undesirable and highly undesirable classes, with an area of 544.36 ha, cover 67% of the total area. Areas within highly desirable and desirable classes, which could be optimal sites for emergency shelter, cover only 4% and 8% of District 1, respectively. This is due to an extremely pessimistic attitude based on risk aversion. So, under this condition, no optimal site for emergency shelter can be determined in the northern, western, and central parts of District 1. Under extremely pessimistic decision-making conditions, the optimal sites are mostly located in the south and southeast. The total area of optimal sites identified with an extremely pessimistic attitude is equal to 16.37 ha, which is less than the area required (36 ha) for emergency accommodation in District 1. Additionally, the identified sites do not cover the northern and western parts of the region. Therefore, decision-making results with different degrees of risk are used to determine other optimal sites.

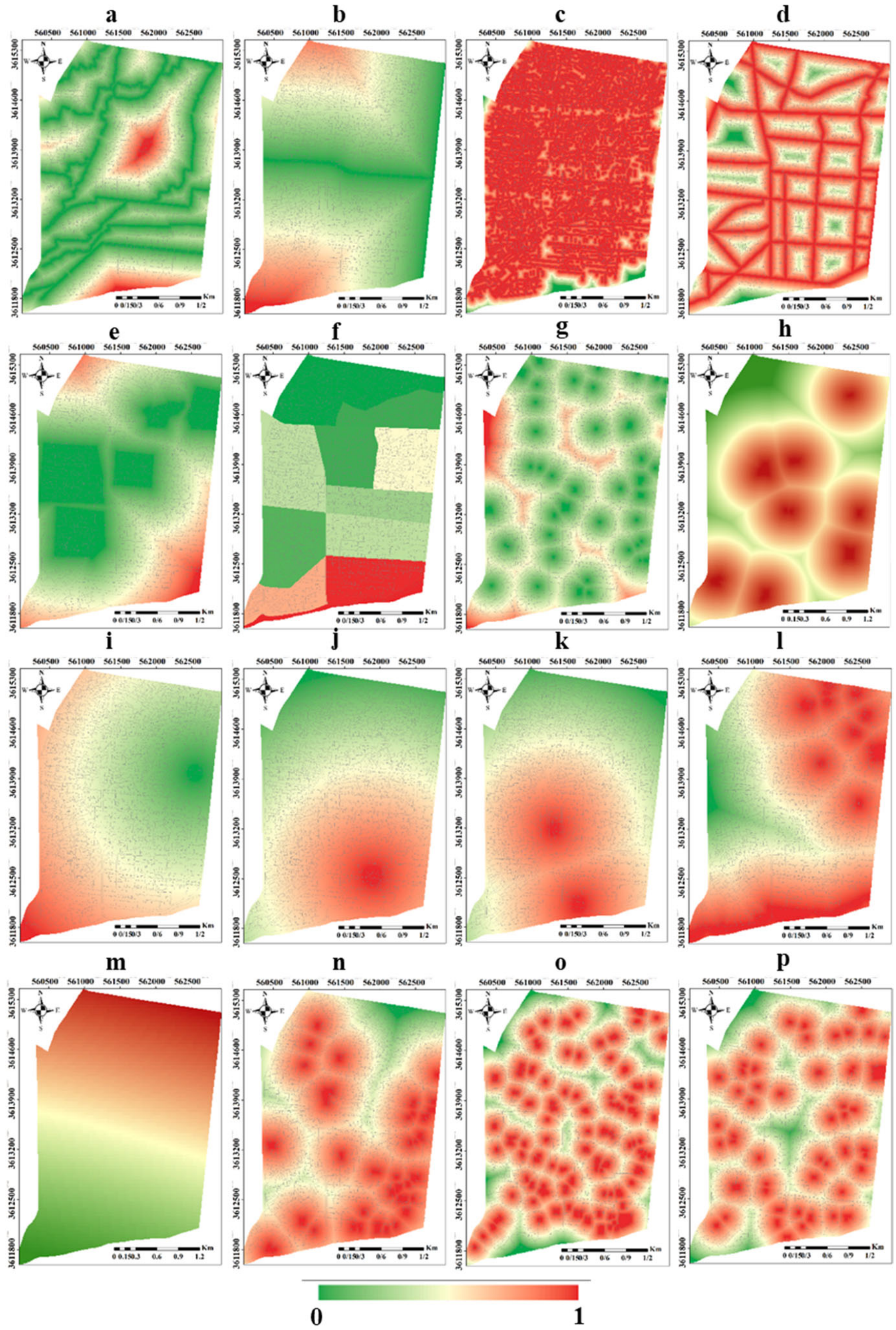

Figure 4. The set of standardized criterion maps, including: (**a**) distance from water canals; (**b**) distance from metro lines; (**c**) distance from minor arterial roads; (**d**) distance from major arterial roads; (**e**) distance from worn-out textures; (**f**) population density; (**g**) distance from hazardous facilities; (**h**) distance from medical centers; (**i**) distance from petrol stations; (**j**) distance from police stations; (**k**) distance from fire stations; (**l**) distance from open spaces and parks; (**m**) distance from faults; (**n**) distance from cultural centers; (**o**) distance from educational centers; and (**p**) distance from sports centers.

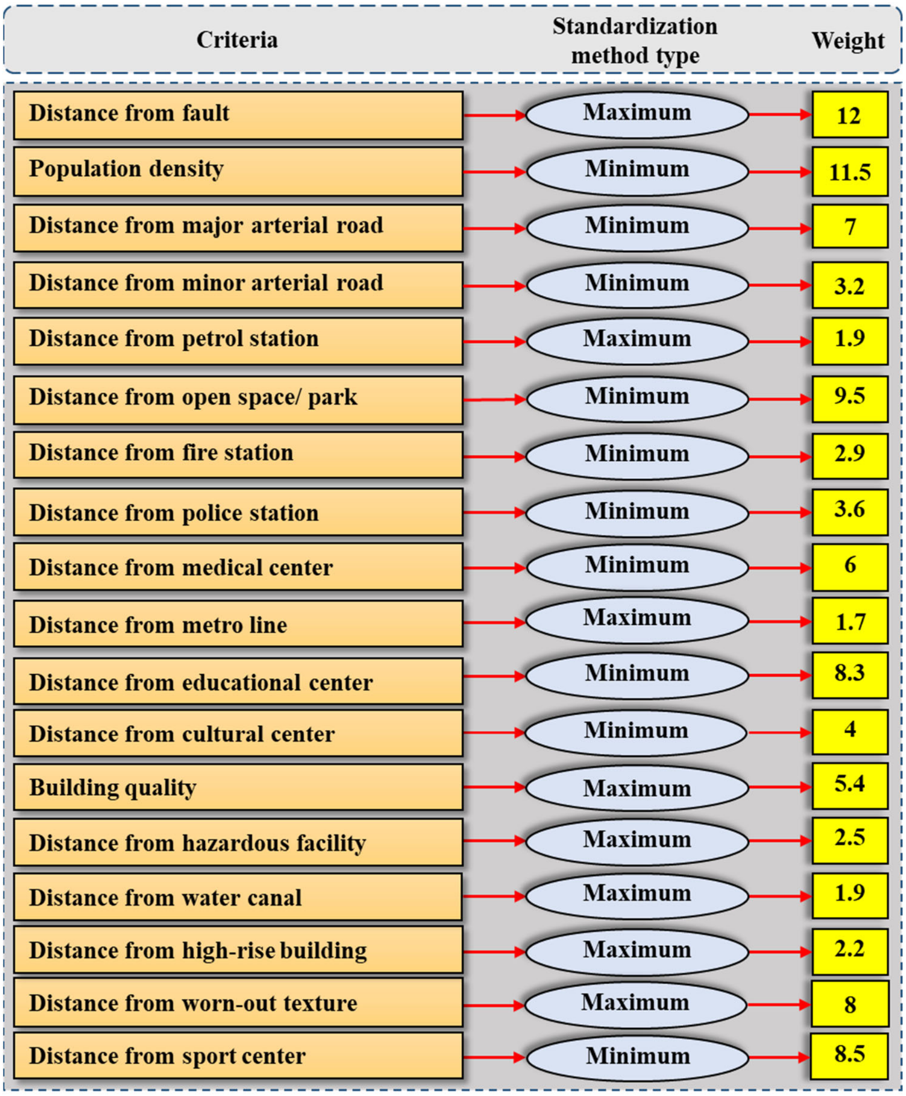

Figure 5. Weight (%) and standardization method of various criteria.

Managers and planners with a neutral attitude toward projects and plans related to the development and equipping of post-earthquake emergency shelters select a balanced mode of decision-making, and are mostly looking for sites to allocate credit where all of the effective criteria have an average state (50%). In the event of a crisis, the efficiency of these locations is expected to reach the intended and predicted level with a probability of 50%. This is because, in these locations, standards are average, and there is a need to increase quality and safety. This attitude is very suitable for conditions where relevant organizations do not face financial limitations. Under neutral decision-making conditions (ORness = 0.5), the areas of highly desirable, desirable, moderate, undesirable, and highly undesirable classes are 87.05, 235.28, 280.85, 171.67, and 39.37 ha, respectively. In this case, the moderate class, with an area equal to 34% of the total area, covers most of the study area. Compared to the previous state (ORness = 0.25), the area of optimal sites increases with an increasing degree of optimism in a neutral attitude toward decision-making. As an example, the areas of highly desirable and desirable classes increased by 3% and 16%, respectively. As a matter of distribution, there are emergency shelters of a highly desirable class in all parts of the region, but some of these locations need to be retrofitted and standardized for earthquakes. The area of the optimal sites identified at this attitude (31.1 ha) is still less than the required area (36 ha) for emergency accommodation in District 1, but in terms of distribution, they cover different parts of the region.

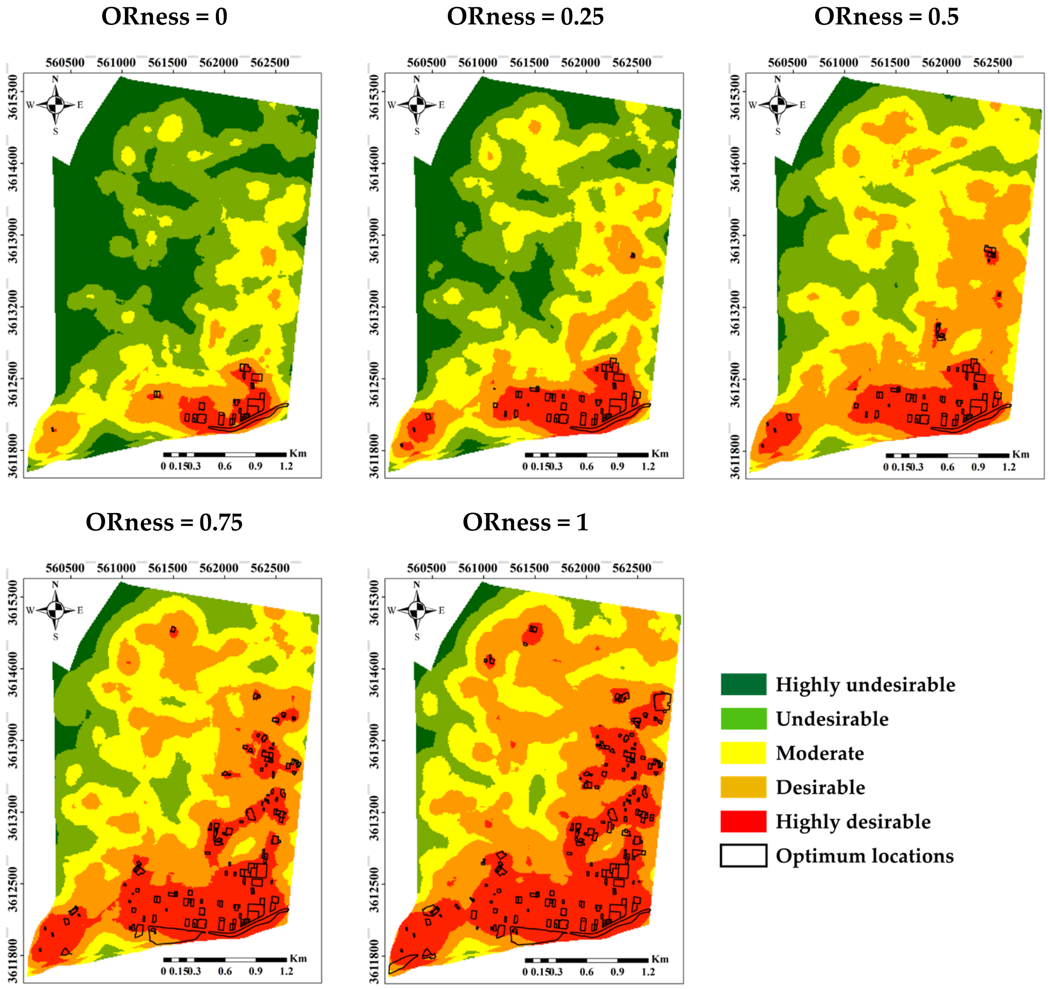

Figure 6. Desirability maps and optimum locations in the study region based on different ORness values.

Under optimistic decision-making conditions (ORness = 0.75), the areas of highly desirable, desirable, moderate, undesirable, and highly undesirable classes are 158.29, 261.9, 248.21, 121.89, and 23.93 ha, respectively. Most of the region is occupied by the desirable and moderate classes, which cover 32% and 31% of the total area, respectively. There has been an increase in the area of optimal locations identified in the region compared to the previous state (ORness = 0.5). The areas of highly desirable and desirable classes have increased by 8% and 3%, respectively. According to criteria in the site selection process, locations selected under optimistic decision-making conditions are of minimum quality and should only be considered as a last resort. The total area of the emergency shelter locations identified is 36.2 ha, which almost provides the required area (36 ha) for emergency accommodation in District 1. In terms of distribution, the chosen sites adequately cover all parts of the study area. These locations need essential equipment so that evacuation and rescue operations can be carried out without disruption or the wasting of time during earthquakes.

Under highly optimistic decision-making conditions (ORness = 1), risk-taking managers and planners in projects and plans related to the development and equipping of emergency shelter sites agree to allocate credits for locations that have the minimum qualification in most of the effective criteria. These locations are less effective and efficient as post-earthquake emergency shelters, since the criteria are less desirable, and they only meet the basic and minimum criteria for emergency housing. Attitudes like these are appropriate and practical in situations where the characteristics of the study area limit the optimal criteria at some sites, and the relevant organizations must choose at least a few emergency shelters. Under highly optimistic decision-making conditions, the areas of highly desirable, desirable, moderate, undesirable, and highly undesirable classes are 228, 312, 189, 69.2, and 16.02 ha, respectively.

The desirable class, with an area of 38% of the total area, covers most of the study area. The areas of sites identified as highly desirable and desirable classes in relation to the riskiness of the decision-making space under highly optimistic decision-making conditions are 28% and 38% of the total area of District 1, respectively. According to the candidates selected based on specific criteria in the selection process, only the basic conditions of emergency accommodation exist at these locations. Therefore, it is vital to build emergency shelters that meet the standards and are distributed according to location.

The desirability maps of emergency shelter sites for District 1 based on five different values of ORness (Figure 6) show that the central, western, and southern parts of the district have more optimized sites than the northern and eastern parts in terms of desirability and numbers. The area percentage of different desirability classes for emergency shelter sites at different ORness levels is shown in Figure 7. As the ORness value increased, the area of appropriate classes for emergency shelter sites (highly desirable and desirable classes) increased, whereas the area of inappropriate classes (undesirable and highly undesirable classes) decreased. For example, the areas of the highly desirable class under extremely optimistic, optimistic, neutral, pessimistic, and extremely pessimistic decision-making conditions are 228.03, 158.29, 87.05, 68.53, and 30.48 ha, respectively. The area of highly desirable class in the district has increased from 4% under extremely pessimistic attitude (ORness = 0 or risk aversive) to 28% under extremely optimistic attitude (ORness = 1 or risk-taking). In contrast, the area of highly undesirable class has decreased from 31% in ORness = 0 to 2% in ORness = 1, which indicates the impacts of the different risk levels in decision-making.

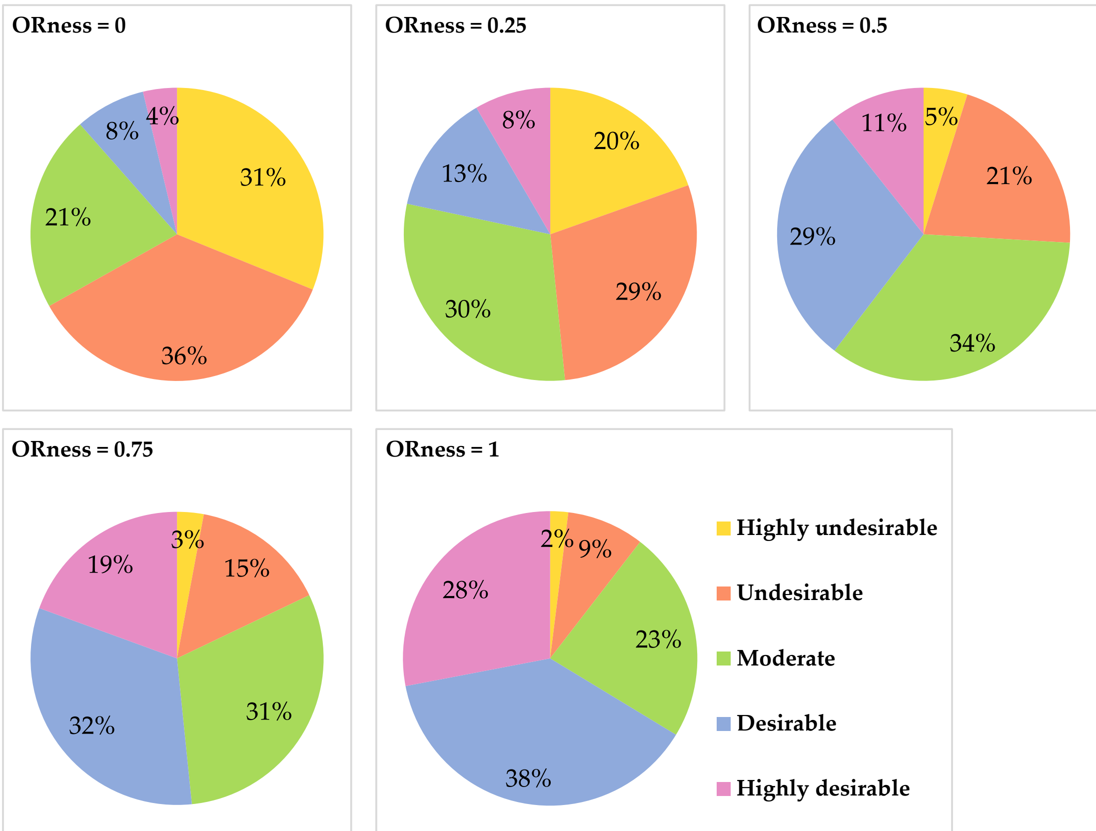

Figure 7. The percentage of different classes in the study area for different values of ORness.

We complied with the following three conditions to determine the optimal sites for emergency shelters in the highly desirable classes obtained from various scenarios that are worth planning: (i) being public, (ii) being under the ownership of the municipality or urban organizations, and (iii) having an area of more than 0.2 ha. Figure 6 illustrates the optimal sites including parks, educational area, hospital, etc., for emergency shelters in the region, while accounting for different scenarios of risk-taking/risk-aversion. According to Figure 6, decision-making risk is directly correlated with ORness, so that higher ORness values correspond to higher decision-making risk and vice versa. A risk-averse decision-maker considers ideal conditions and maximum expectations in decision-making. Hence, among the different options, the decision-maker selects the one that has ideal conditions in terms of various criteria. This is why the number of optimal emergency shelter options is limited. In contrast, the risk-taking decision-maker is in a completely opposite situation (Figure 6).

As the findings suggest, the OWA model, with its high degree of flexibility in combining different input criteria, can provide the results of a spatial decision-making problem with various degrees of risk. In view of all that has been mentioned so far, a risk-averse decision-maker is looking for sites where all the criteria are in the optimum condition. Hence, the number of optimal emergency shelter sites is limited. The advantages of this approach may be briefly summarized as follows: (i) not having issues of inconsistency in the opinions of a small number of experts; and (ii) cost management in procuring emergency shelters by considering the degree of decision risk. The disadvantages of this approach are its time-consuming implementation and high processing volume. Moreover, the used data were collected from different sources.

5. Conclusions

For the first time, this study has utilized a decision-making support system based on collective intelligence to select post-earthquake emergency shelters. This system used 18 influential criteria and calculated the relative importance (weight) of each criterion using the LGDM method. Maps were also created indicating the suitability of potential shelter sites, and these sites were prioritized based on different levels of risk. This approach provides a scientifically grounded plan for earthquake resilience planning.

Using the risk-driven Large Group Decision-Making support system, managers and planners can purposefully decide how to improve and equip post-earthquake emergency shelters according to the risk degree in planning. In this study, five decision-making scenarios were implemented, while the developed decision-making support system has the ability to create scenarios based on other degrees of risk (from zero to one, 100 scenarios). In addition to its flexibility, this system can be applied to different types of mental conditions in managers and planners. Therefore, the optimal emergency shelter sites determined for various regions differ based on ORness values. As the degree of optimism increases, the area of very highly desirable and desirable classes increases. In the same way, as the degree of optimism decreases, the area of highly undesirable and undesirable classes increases. Risk-averse managers and planners could use the results of this study to allocate more resources to those locations that meet all relevant criteria at optimal levels in plans related to the development and equipment of emergency shelters, because, in this case, they will more likely achieve the intended efficiency. The area of suitable sites identified in highly desirable and desirable classes under highly pessimistic decision-making conditions is only between 4% and 8% of the total area of District 1. Our findings show that there are no optimal sites for emergency shelters available in the northern, western, or central parts. In the southern and southeastern parts of District 1, parks and educational centers are identified as optimal sites. GIS and MCDM were integrated in this study to determine the optimal locations for post-earthquake emergency shelters based on collective intelligence. Therefore, it is recommended that responsible organizations make an effort to incorporate such systems, as they provide the basis for decision-making regardless of individual preferences and tendencies, and provide a data-driven approach for selecting optimal sites for emergency shelters. In future studies, it is suggested to integrate the capabilities of the OWA method with fuzzy logic in order to reduce the uncertainty of the results.

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