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Analysis of the Vulnerability of Pilgrims in Imam Reza's Shrine during the Emergency Evacuation Due to the Crisis using Fuzzy Logic and Interpolation Method

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Original Article

Abstract

INTRODUCTION: The need to carry out the emergency evacuation of people from disaster-affected areas and their transfer to safe areas, in the shortest possible time and with the least number of injured, has made the issue of urban emergency evacuation a complex one in the real world. The complexity of the spatial layout of the courtyards and the presence of a large population within the Shrine, among which vulnerable groups also have a significant share, increase the probability of the population's vulnerability to natural and human disasters. Based on this, the current research was conducted to investigate the vulnerability of the pilgrims of Imam Reza's Shrine during the emergency evacuation caused by the crisis and what measures could reduce the vulnerability.

METHODS: The present applied study was conducted based on a descriptive-analytical method. The required data were collected through documentary-library and field studies methods. The gathered data were analyzed using the Analytic Hierarchy Process model, fuzzy logic, and the Inverse Distance Weighting interpolation method in Arc GIS and Expert Choice software.

FINDINGS: The findings of this study indicated that based on the presented integrated model, which included 7 variables of the length of the route, the number of nodes along the route, the number of nodes in the surrounding space of the settlement, fixed and passing population density, the ratio of the population to the width of the exit door, and distance from buildings, the highest level of a possible vulnerability in the Shrine was related to Rozeh Monavvareh, Goharshad Courtyard, Sheikh Bahaie Sanctuary, the western part of the Great Prophet Courtyard, and Bab-Al-Javad in descending order. The north and northeast parts of the Shrine had a low level of vulnerability for people's exit.

CONCLUSION: The results of this research showed that the presented model could be used as a suitable model in other religious places. In addition, some measures can be adopted to reduce the vulnerability of pilgrims, including increasing the number and width of the doors, removing obstacles in the place of the doors, and paying attention to the type of activities assigned to different parts of the Shrine.

Keywords: Emergency evacuation; Fuzzy logic; Shrine of Imam Reza; Interpolation method; Vulnerability analysis

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Introduction

One of the general strategies and main activities in managing a crisis caused by unexpected events is the emergency evacuation of people who have been saved from disasters in the affected area. The main issue in emergency evacuation management is to guide people in the optimal routes to reach the desired safe areas. The need to carry out the emergency evacuation of people from disaster-affected areas and transfer them to safe areas, in the shortest possible time and with the least number of injured, as well as the behavior of

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people and the effects of environmental factors in the urban space, have made the issue of urban emergency evacuation be raised as a complex issue in the real world.

Imam Reza's Shrine receives a large number of visitors daily. The complexity of the spatial layout of the courtyards and the presence of a large population within the Shrine, among which vulnerable groups also have a significant share, increase the probability of the population's vulnerability to natural and human disasters. Based on this and in line with the main issue mentioned, the current research discussed how vulnerable pilgrims were in different parts of the Shrine of Imam Reza during the emergency evacuation caused by the crisis and through what measures the level of vulnerability could be reduced. What makes the current research different from other studies conducted in this field was the absence of a study regarding the emergency evacuation of religious places in the country. In other words, one of the scientific (theoretical) goals of this research was to provide a repeatable study model regarding the emergency evacuation of the population of other religious places in the country in times of crisis.

In relation to the topic of the present research, a few studies have been conducted in the country so far, among which the following research can be mentioned. The results of a study showed that physical and architectural interventions in Imam Reza's Shrine could be reviewed with a passive defense approach, which would reduce casualties due to terrorist threats (8). It should be noted that the mentioned research was different from the present research in terms of its nature and method. In another study, the researchers used the random cellular automata model to study emergency evacuation (10), and recommended that in spaces with two exit doors, the optimal condition of evacuation was that the exits be symmetrical in plan and be located in a distance not too short nor too long from each other. They also showed that the average flow rate through an exit door (people per second) was a non-linear function of the width of the exit door with a decreasing slope.

The results of another study provided multi-stage optimal modeling for discharge (11). This model was a random search method to determine evacuation routes in crowded places. This simulation model was used to record the density along the route. The researchers of another study used the cellular automata model to simulate the evacuation process of a room in two cases with and without obstacles, and by comparing the traffic flow through different doors; they concluded that the use of a double door instead of two separate doors did not improve the evacuation (14). Moreover, by increasing the outlet width to about 3 m, the evacuation time was reduced.

In another research, the evacuation of a five-story school building was investigated (13). The building had a staircase with a width of 1.5-2 m. The classes included 70 students with two exit and evacuation doors with an equal division between the two doors. The results showed that the age of the evacuees (for the age range of the elementary school) had a direct relationship with the speed of evacuation and as the age increased, the total evacuation time decreased. The researchers of another study examined the evacuation of multi-story buildings during earthquakes and fire in a case study of a 12-story university building (16). To this aim, the mentioned study used the structure of the building (e.g., plan, location of the stairs, usage status of the rooms, and distribution of the population) and the observed information on the evacuation of people in the simulation of possible scenarios during the crisis (e.g., blockage of a staircase in the floors).

In a research, titled a GIS-based optimum route determination for emergency evacuation the road network of district 7 of Tehran was tested using the Dijkstra basic model for optimal routing that was optimized for earthquakes by being limited to some special conditions (4). The research results indicated that to determine the optimal route in a real urban network with 432 building block nodes, 11 safe zone nodes, and 1,189 edges, only about 90 sec was needed.

In a study titled Optimal Model of Emergency Evacuation of The Population after an Accident in Urban Areas Using Genetic Algorithm (Case Study of District 3 of Kerman City), the opinions of experts were used to identify effective indicators and criteria for emergency evacuation, the Expert Choice software in GIS and the genetic algorithm to rank the criteria due to its simplicity and high speed for analyzing high-dimensional networks to reach safe spots (5). The results of the research indicated that the proposed method found the shortest path to reach the safe points while considering the population density and the width of the roads.

A study titled Node Traffic Simulation Model of an Earthquake with Fuzzy AHP Using GIS Samples, Tehran Municipality, District 3, was conducted to investigate the most traffic nodes in 5 ranges of very high, high, medium, low, and very low in different areas of District 3 of Tehran and in relation to earthquakes with the magnitudes of 6, 7, and 8 (3).

Another research was carried out to predict traffic access network performance after the occurrence of a crisis using the space layout method (7). In this study, to perform the analysis, the centerline of roads in the 6th District of Tehran was entered as the statistical population of the research in the GIS software environment and was evaluated with the Ox one Plug-in, and the parameters of the analysis of the space arrangement method were extracted from it (7).

The review of the conducted studies revealed that in the field of emergency population evacuation, research has been conducted using different methods and software, each with its own advantages and disadvantages. The use of GIS software is often observed in these studies. According to the research problem that was stated earlier, the analysis in this research was performed by building/ pedestrian-based emergency evacuation simulation models (group of agent-based simulation models) inside the Shrine, as well as using the Analytic Hierarchy Process (AHP) model, fuzzy logic (decision-making models) model, and the Inverse Distance Weighting (IDW) interpolation method within the framework of using Arc GIS and Expert Choice software.

Methods

This applied research was conducted based on a descriptive-quantitative method. The research approach was descriptive-analytical, and the required data were collected through documentary-library and field studies methods. The statistics related to the features of the different spaces of the Shrine, including the population and area, were gathered based on the data available in the Shrine, and the data related to other variables were collected through the authors' field studies, as well as the results of the expert team's opinion (related details are given in the following).

The analysis in this research was performed within the Shrine and using the AHP model, fuzzy logic (decision-making models) model, and IDW interpolation method in the framework of using ArcGIS and Expert Choice software. To determine the variables of the research, first by examining the previous studies, a set of variables was extracted and then the extracted variables were given to 5 university professors in the field of urban and crisis management and 5 experts in the field of crisis and passive defense in Mashhad municipality, and they were asked to announce the most important variables.

It should be noted that the aforementioned people had the right to add a variable or variables to the set of previous variables. After this stage, the final variables were extracted according to the summation of the experts' opinions, and finally, the variables were provided to the experts for a binary comparison between them. After the summation of the weights obtained from the opinions of the experts, and since the compatibility rate of the system was less than 0.1, the validity and reliability of the variables were confirmed. The final extracted variables included seven variables, namely 1) the length of the route, 2) the number of nodes (doors) along the route, 3) the number of nodes (doors) in the surrounding space of the settlement, 4) fixed population density in the surrounding area of the settlement, 5) passing population density, 6) the ratio of the population to the width of the exit door, and 7) distance from buildings.

The buildings and open spaces occupy an area of 394,848 m2 (39.4 hectares) of the Shrine. The total area of the buildings in the Shrine is 158,553 m2 (40.16% of the total area of the Shrine), while the area of open spaces in the Shrine is estimated at 236,295 m2 (59.84% of the total area of the Shrine). (Figure 1)

Fuzzy logic model

Fuzzy logic is a multi-valued logic, that is, its parameters and variables, in addition to having the numerical value of 0 or 1, can have all the values between these two numbers. The belonging of each member of the reference set to a specific sub-set member is not certain, that is, it cannot be said with certainty whether the member in question belongs to this set or not. This uncertainty is done by assigning a number between 0 and 1 to this member (12).

Its formula is as follows:

$$F(x_i) = \frac{Xi - Xmin}{Xmax - Xmin}$$

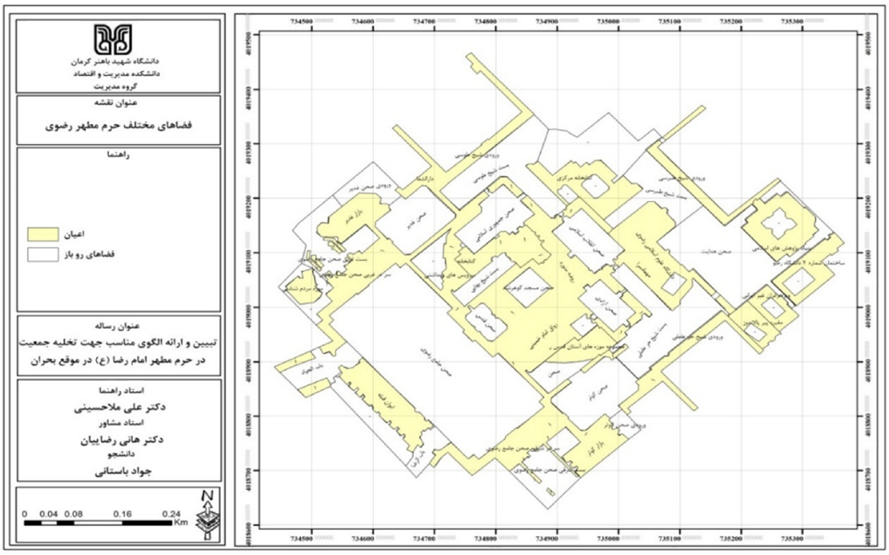

Figure 1. Different parts of Imam Reza's Shrine

Analytic Hierarchy Process

The AHP is one of the best and most accurate ranking and decision-making methods based on several indicators (1). One of the features of this method is the possibility of using such software as Expert Choice, allowing users to use this method with high speed and accuracy (1). The AHP starts with identifying and prioritizing decision-making elements. These elements include objectives, criteria or characteristics, and possible options that are used in prioritization (9). Therefore, the first step in the AHP is to create a hierarchical structure of the subjects under investigation, in which goals, options, and the relationship between them are shown. The next four steps in this process include calculating the weight (importance factor) of criteria and sub-criteria, calculating the weight (importance factor) of options, calculating the final score of options, and checking the logical compatibility of judgments (2). In this method, pairwise comparisons of decision-making options and criteria are used to calculate the weight of the criteria and sub-criteria. In these comparisons, the decision-makers will use verbal judgments, so that if the element i is compared with the element j, the decision-maker will say that the importance of i over j is one of the states mentioned in Table 1. After determining the importance of the criteria relative to each other, the compatibility rate of the system should not exceed 0.1, otherwise, the weights should be revised (6).

Table 1. Preference values for pairwise comparisons

Numerical value	Preference level
1	Equally preferred
2	Equally to moderately preferred
3	Moderately preferred
4	Moderately to strongly preferred
5	Strongly preferred
6	Strongly to very strongly preferred
7	Very strongly preferred
8	Very strongly to extremely preferred
9	Extremely preferred

Source: Qoudsipour, 2008: 14

Inverse Distance Weighting interpolation method

The IDW interpolation method is based on the assumption that the effect of the desired phenomenon decreases with an increase in the distance. In other words, the continuous phenomenon in the unmeasured points is the most similar to the nearest measured points; therefore, to estimate the unknown points, the surrounding samples should be more involved than those that are further away. In this model, distance is used as the weight of the known variable in predicting the unmeasured points because the role of the continuous variable in the influence decreases with the distance from the location of the unknown point. Therefore, as the distance from the known point to the unknown point increases, it is necessary to reduce the weights based on the distance, so the

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distances are reversed. In other words, the inverse of the distance is used as the weight of the measured points in predicting the unknown points. This is the reason why this model is called Inverse Distance Weighted. Moreover, the effect of the intensity of spatial dependence in the data can be applied using the power in the inverse of the distance. The inverse square of the distance from this model has been used repeatedly by researchers (15).

Findings

The steps of analyzing the findings in this research in the form of 7 variables mentioned in the research method section are as follows:

Since it was not possible to distribute questionnaires among the people inside the Shrine, a team was formed consisting of a male servant, a female servant, an expert from the Astan Quds Razavi administration, and an expert in the field of crisis and passive defense of Mashhad municipality. Afterward, 120 hypothetical points were considered in different parts of the Shrine, so that all parts of the Shrine were covered. Next, the team members were asked to be located in the considered points and choose the best route. The results of the decisions of this 4-person team were drawn in the form of the optimal route from each of the 120 points on the GIS map, and finally, according to the considered route, the actions mentioned in the following 3 steps were carried out. (Figure 2)

The first step: included three stages as follows:

- Preparation of GIS layers related to each of the variables/indicators
- Fuzzification of the layers prepared in the previous step; at this stage, the indicators were aligned in terms of direction and size. The range

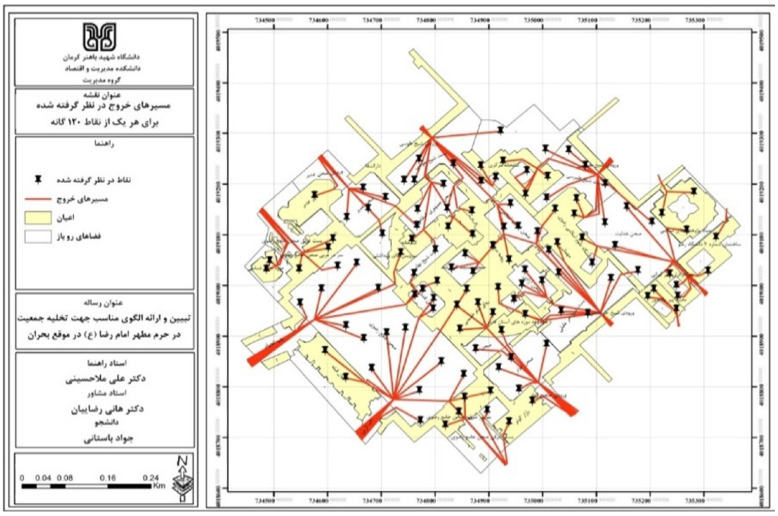

Figure 2. Considered exit routes for each of the 120 points

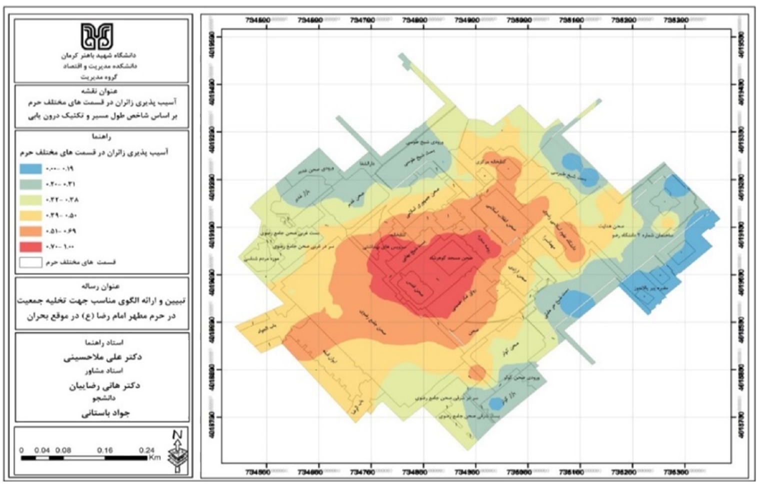

Figure 3. Vulnerability of pilgrims in different parts of the Shrine based on the fuzzified route length index and interpolation method

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- of values from zero to one was considered in such a way that zero was the lowest level of vulnerability and one was the highest level of vulnerability for each of the 7 indicators.
- Interpolation of the fuzzified layers on the entire area of the spaces in the Shrine (the meaning of the interpolation method is given in the research method section);
- The second step: weighting variables/indices based on their binary comparison (based on the process of hierarchical analysis)

The third step: included 2 stages as follows:

- Determining the final score (vulnerability) of each of the considered points;
- Interpolation of the final score on the general area of the spaces in the Shrine.

The first step:

As stated earlier, this step consisted of 3 stages, and due to the limitation of the volume of the article, the output of the third step of this step was presented in relation to each variable.

1. The length of the route: The route length was calculated according to the exit route map for each of the 120 points. Obviously, the longer the route, the greater the potential vulnerability. It should be noted that the drawing of the vulnerability level was done on the 120 points. As can be seen in Figure 2, the maximum level of people's vulnerability during emergency exit based on the route length index was related to the central parts, which decreased with the distance from Rozeh Monavvareh.

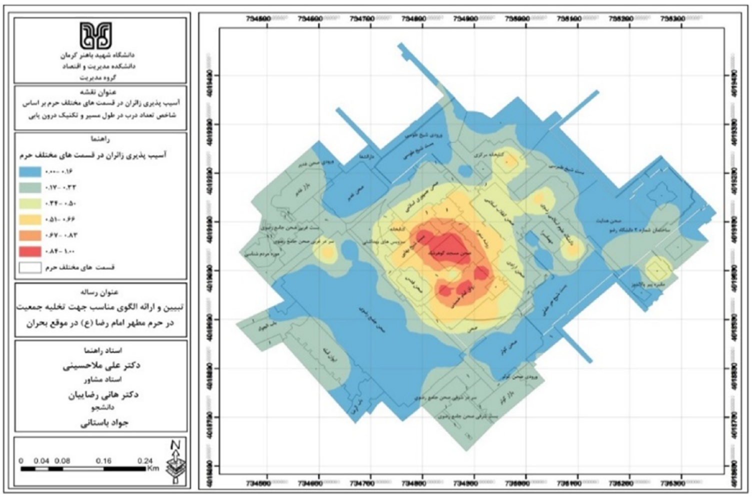

Figure 4. Vulnerability of pilgrims in different parts of the Shrine based on the fuzzy index of the number of doors along the route and the interpolation method

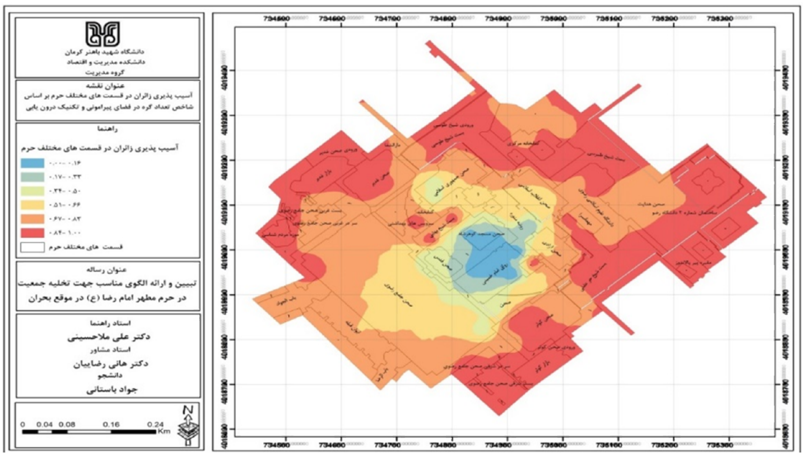

Figure 5. Vulnerability of pilgrims in different parts of the Shrine based on the fuzzy index of the number of nodes in the surrounding space and the interpolation method.

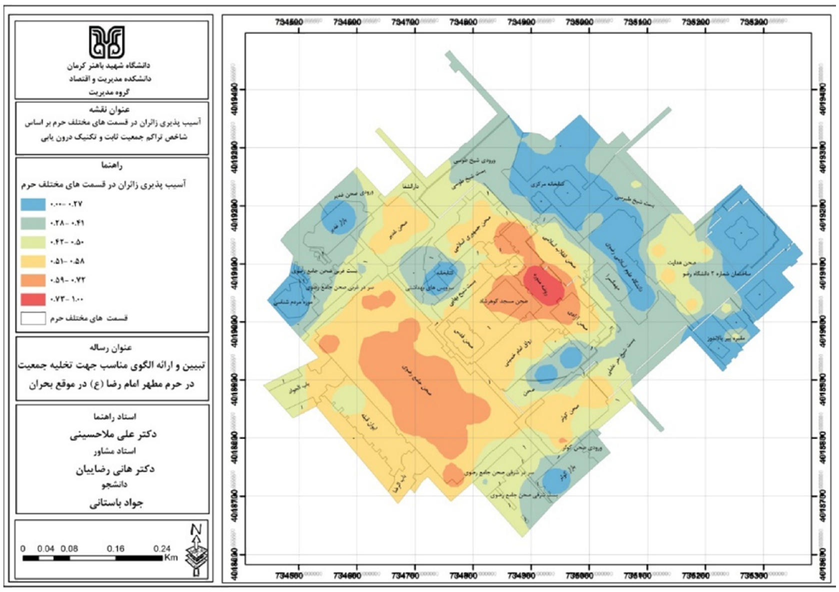

Figure 6. Vulnerability of pilgrims in different parts of the Shrine based on the fuzzy fixed population density index and interpolation method

2. The number of nodes (doors) along the route: According to the map of exit routes considered for each of the 120 points, the number of doors along the route was calculated. Obviously, the more the number of doors along the route, the greater the vulnerability of those present in the Shrine. As can be seen in the relevant map, the highest level of vulnerability of the different parts of the Shrine based on the fuzzy index of the number of doors along the route was related to the central parts (Rozeh Monavvareh).

3. The number of nodes (doors) in the surrounding space of the settlement: Obviously, more doors in the settlement would increase the number of choices. Therefore, if a route was blocked for a reason, there would be alternative routes. By increasing the number of doors in the place of settlement, the probability of vulnerability of the people present in the Shrine would decrease. For the analysis of this part, the 4-person team was asked to announce the best route from their point of view after being placed at the desired point. After the announcement, the number of routes was determined by the number of surrounding doors. The lowest level was equal to 1 (the highest level of vulnerability) and the highest level was equal to 4 (the lowest level of vulnerability). As can be seen in the relevant map (Figure 2), the highest levels of vulnerability were related to the northern, eastern, and southern parts. In other words, Sheykh Toosi Sanctuary, Sheikh Tabarsi Sanctuary, and Sheykh Hurr Ameli Sanctuary and their surroundings were among the most vulnerable areas.

4. Population density in the surrounding area of the settlement: The higher the density of the population around the settlement, the slower the speed of movement and the higher the probability of vulnerability. Obviously, population density would be divided into two categories, namely fixed population density and passing population density. Fixed population density is the population density that exists in the place at the moment of crisis, while the passing population density is the population density that is added to the density of the fixed population by the entry of other populations due to the immediate spaces of the existing space. As can be seen in the relevant map, the highest level of vulnerability based on the fuzzified fixed population density index was related to Rozeh Monavvareh and the southwest parts of the Shrine (Great Prophet Courtyard) and its surroundings. As can be seen in the relevant map, the highest level of vulnerability of pilgrims in different parts of the Shrine based on the fuzzified passing population density index was related to Sheikh Bahaie Sanctuary, followed by Sheykh Toosi Sanctuary and Azadi Courtyard.

5. The ratio of the population to the width of the exit door: The higher this ratio, the higher the probability of vulnerability. Based on the fuzzified index of the ratio of the population to the width of the doors, as can be seen in the map, the highest level of vulnerability was related to the southwest

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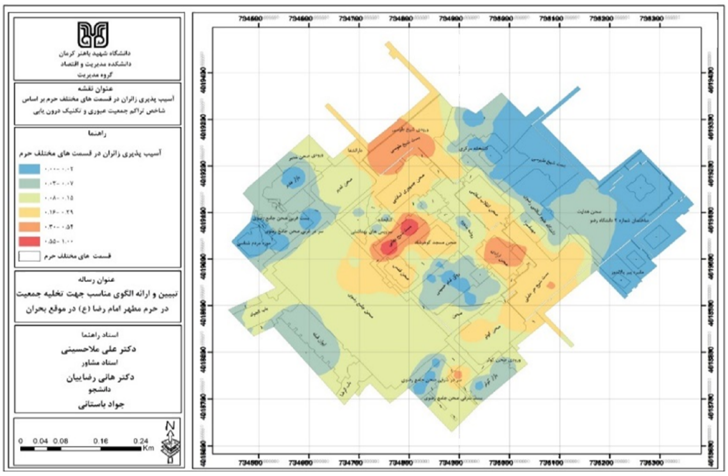

Figure 7. Vulnerability of pilgrims in different parts of the Shrine based on the fuzzy index of passing population density and the interpolation method

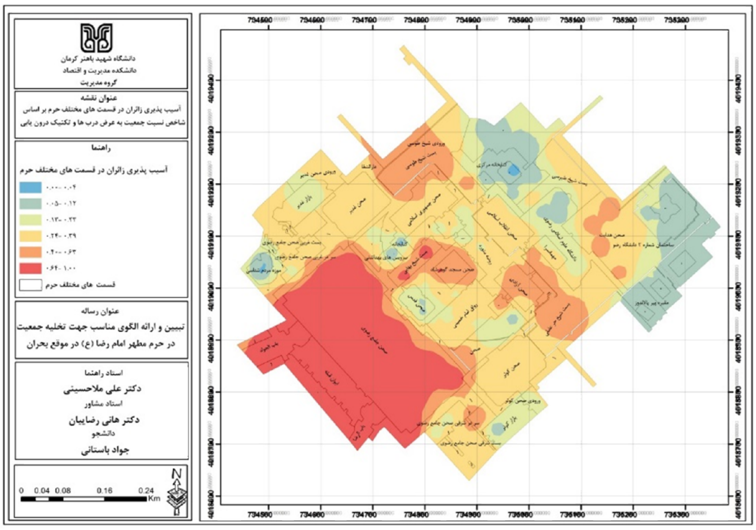

Figure 8. Vulnerability of pilgrims in different parts of the Shrine based on the fuzzy index of the ratio of the population to the width of the doors and the interpolation method

part of the Shrine (Great Prophet Courtyard) and its surroundings, followed by Sheykh Toosi Sanctuary, Sheikh Bahaie Sanctuary, Sheykh Hurr Ameli Sanctuary, and Azadi Courtyard.

6. Distance from buildings: The level of vulnerability of people in indoor areas is higher than in outdoor areas. Therefore, the greater the distance from the buildings, the lower the level of vulnerability. As can be seen in the relevant map, the lowest level of vulnerability based on the index of distance from the buildings was related to the Great Prophet Courtyard. The vast area of this courtyard would create more space away from the buildings for gathering.

The second step: weighting the variables/indices based on the pairwise comparison;

To determine the weight of each indicator, based on the AHP model, a pairwise comparison of indicators with each other was conducted. All measures at this stage were carried out within the framework of using Expert Choice software, the output of which (determining the final weight) was as follows:

Route length index=0.074, number of doors along the route=0.296, number of nodes in the surrounding space=0.148, fixed population density=0.148, passing population density=0.148, ratio of population to door width=0.148, distance from buildings=0.037.

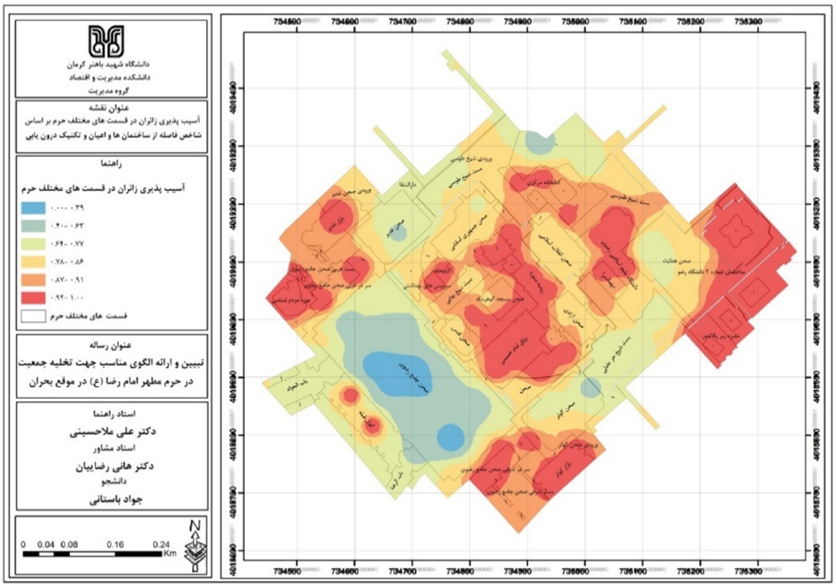

Figure 9. Vulnerability of pilgrims in different parts of the Shrine based on the fuzzy index of the distance from buildings and the interpolation method

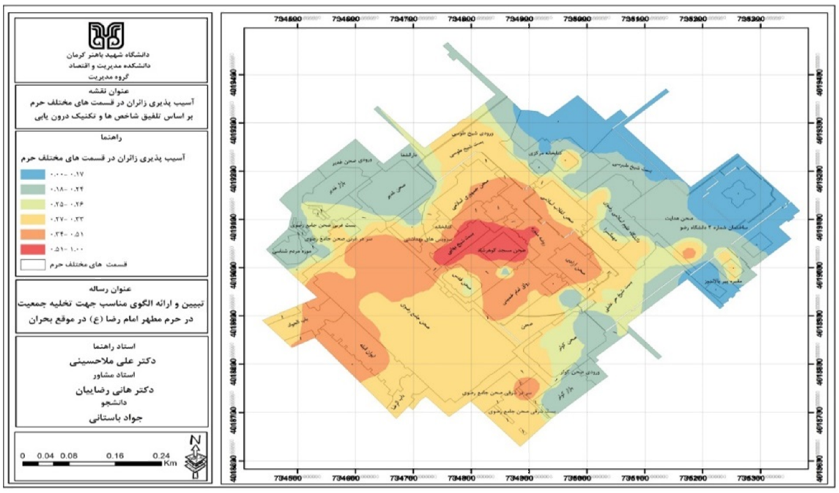

Figure 10. Final map of the vulnerability of different parts of the Shrine based on the combination of indicators and interpolation technique

The third step: determining the final score (vulnerability) of each of the considered points and interpolating the final score on the entire area of the spaces in the Shrine.

In this step, first, the final score of each of the 120 considered points was calculated. In the following, using the interpolation method, the entire area of the spaces in the Shrine was analyzed in terms of vulnerability. As can be seen in the Figure 3, the maximum possible vulnerability was related to the Rozeh Monavvareh to the south (i.e., the Goharshad Courtyard), Sheikh Bahai Sanctuary, the western part of the Great Prophet Courtyard, and finally Bab-Al-Javad. The north and northeast parts of the Shrine had a low level of vulnerability.

Discussion and Conclusion

This study aimed to investigate the vulnerability of pilgrims in the Shrine of Imam Reza during the emergency evacuation caused by the crisis. Based on this, the analysis in this research was conducted in the Shrine and using the AHP model, fuzzy logic (decision-making models), and IDW interpolation method within the framework of using Arc GIS and Expert Choice software. The results of the analysis of the vulnerability of different parts of the Shrine during the emergency evacuation due to the crisis indicated that the greatest possible vulnerability

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was related to the Rozeh Monavvareh towards the south, which was to the Goharshad Courtyard, Sheikh Bahai Sanctuary, the western part of the Great Prophet Courtyard, and finally Bab-Al-Javad. The north and northeast parts of the Shrine had a low level of vulnerability.

Acknowledgments

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Conflict of Interests

The authors declare that there is no conflict of interest in this study.

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