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A Model for the Network of Relief Centers during an Earthquake in the Central area of Tehran, Iran

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Original Article

Abstract

INTRODUCTION: The network of relief centers, which is a connected set of relief centers, rescue points, and rescue routes, is of utmost importance during an earthquake. This study aimed to model this network to identify the aid-receiving points and rescue routes, followed by the development of plans to improve the aid-giving process during an earthquake.

METHODS: This descriptive-analytical study was conducted based on an applied research method and a quantitative approach. The required data were obtained through the library method (documents). The data used in this study included location information of relief centers (hospitals, crisis management centers, Red Crescent Society centers) and the transportation routes among them. These pieces of information were collected from related plans and documents. The obtained data related to the location of relief centers were analyzed using Spatial Analysis, and Network Analysis tools were utilized to analyze the transportation routes among the relief centers.

FINDINGS: The findings in this study revealed the right places for receiving aid and the rescue routes that deliver aid from the aid-giving to the aid-receiving centers in the central area of Tehran in the shortest time. Moreover, the relief centers were ranked based on their importance during a crisis.

CONCLUSION: The results of this study show the number of required aid-receiving points in the central area of Tehran through which the aid needed during a crisis can be delivered from rescue centers. The findings revealed which relief centers played a more significant role during an earthquake. The identification of these points and routes makes the provision of special planning possible during an earthquake.

Keywords: Earthquake; Network of relief centers; Network analysis; Relief routes; Spatial analysis; Tehran

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Introduction

Cities as complex systems are prone to natural disasters. Despite efforts to minimize vulnerability to disasters, the number of financial losses and casualties continues to increase (1). Since earthquakes have the potential to cause large damages and widespread disruption in society, they have been given high priority to increase resilience in society (2). Accordingly, several studies have been conducted in this regard owing to the heavy loss of human life and financial damages caused by the earthquake.

As one of the earthquake-prone regions of the world, 950 earthquakes occur annually in Iran, and in the last century, 144 earthquakes with a magnitude of more than 5 on the Richter scale have been recorded in this country (3). Meanwhile, according to the zoning divisions of relative earthquake risk, Tehran, as the most important metropolis of Iran, is located in an area with a very high seismic risk (4). According to historical records, Tehran has suffered several

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severe earthquakes with return periods of 150 years, and this city has not experienced a disastrous earthquake since 1831. Therefore, there is a high probability that a devastating earthquake will occur with a magnitude of more than 7 on the Richter scale in this city at any moment (5).

Tehran as the capital of Iran with the highest rate of urban population and activities possesses a significant and vital economic, political, and social position. However, this city suffers from inappropriate unsafe conditions due to non-observance of safety principles (e.g., construction in fault zones and areas prone to geological instability), inappropriate design and construction of buildings, as well as key facilities with possible seismic intensity, lack of necessary operational plans and capabilities for disaster management in the response phase and dealing with the consequences of an accident, and the existence of many vulnerable and worn-out urban context (6).

Accordingly, the central area of Tehran (Districts 6, 7, 11, 12) is highly vulnerable to earthquakes due to worn-out urban context, narrow thoroughfares, population density, and activity close to the Ray fault. The results of studies conducted in these districts, especially 11 and 12, indicated their low resilience against earthquakes. The delay in helping the injured is regarded as one of the main reasons for the high death rate due to earthquakes, which have occurred a lot in the past earthquakes. Accordingly, relief centers play a vital role in the post-accident response phase (7).

In this regard, three remarkable centers that can have a very effective role include hospitals, Red Crescent Society, and crisis management support centers. Studies conducted on these centers, especially hospitals in Tehran, demonstrated their high vulnerability to earthquakes (5&6) and low organizational resilience (9,10,11). The poor condition of these centers during an earthquake leads to much more severe consequences. One of the factors effective in enhancing the efficiency of relief centers is the rescue routes connecting these centers to the points requiring help.

Due to this necessity, many studies have been conducted in terms of routing. Regarding urban emergency vehicle routing, Goldberg and Listowsky (1994) identified the most critical factors affecting this issue, and therefore, the most important factors are time, distance, road quality, and the type of relief road (12). Similarly, Neysani et al. (2006) used prominent urban points in order to route emergency vehicles after a crisis. Moreover, statistical analyzes, such as normality and error tests have been used to locate prominent points (13). Along the same line, Jotshi et al. (2006) have identified the routes of urban emergency vehicles after a crisis in Los Angeles based on the factors that cause a delay in reaching the accident site and hospital (14).

Musolino et al. (2012) have determined appropriate routes for emergency vehicles during emergencies in Italy using static and dynamic traffic data (15). Furthermore, Zolfaghari and Karke Abadi (2013) investigated the intelligent routing of relief teams using genetic, ant colony, and game theory algorithms in Semnan, Iran, and compared the time traveled by each of these routes (16). Arkat et al. (2014) have routed the emergency facilities considering the possibility of communication route failure and emergency facility congestion using network analysis routing algorithms in GIS. In addition, they evaluated the possibility of damage to communication routes due to the collapse of (unlevel) bridges, the destruction of high-rise buildings, the explosion of gas stations, and pressure reduction stations (17).

Kheirollahi and Nadi (2015) have also compared the meta-heuristic genetic algorithm (to select the optimal route) with the conventional Dijkstra's algorithm and showed the superiority of the meta-heuristic genetic algorithm over other existing methods (18). Despite extensive studies on aid-receiving centers and rescue routes, these issues have been investigated separately, and no studies have considered them integrated and connected. Based on network science, the components of a network do not act and affect individually and separately from and on each other. Therefore, the damage caused to one affects the other, and it spreads throughout the network.

During a crisis, since aid-receiving and aid-giving centers are in contact with each other and influence each other, they can be considered a network. This network is activated during emergencies and provides relief in a coherent whole. Every network consists of components and relationships among them; accordingly, modeling a network means accurately identifying the components and relationships among them (19).

Therefore, modeling the network of relief centers is the identification of the components of this network and the relationships among them. Regarding the definition and nature of the network of relief centers, the components of this network are aid-giving/receiving centers, and their relationship is regarded as the transportation routes between them. It should be mentioned that each component has a different influence on the others based on the level of relationships between them and other components in the network. As a result, it is possible to rank the components of a network based on their influence. In this regard, after identifying the aid-receiving centers and transportation routes in the modeling of the network of aid-giving centers, the rescue centers can be ranked based on the number of transportation routes that lead each of them to different points of the aid-receiving centers.

With this background in mind, this study aimed to identify the components and their relationships in the network of relief centers (aid-giving centers) to model this network. In this regard, aid-receiving centers are identified as components, and rescue routes are regarded as their relationships.

Study Setting

This study investigated the central area of Tehran. Initially, the characteristics of the Tehran metropolis are described generally, followed by the description of the central area characteristics of this city in more detail. Tehran is the largest city and capital of Iran, as well as the center of Tehran province. This city with 700 square meters of land area has the GPS coordinates of 35 42' 55.0728" N and 51 24' 15.6348" E. According to the 2015 census, the population of this city is more than 8,693,706 people. This city is located on the slopes of Alborz Mountain, which forms a part of the Alpine-Himalaya mountain range. This zone has high seismic power and numerous active faults.

As shown in Figure 1, the main cause of earthquakes in Tehran is the presence of three main faults, namely Mesha, North Tehran Fault, as well as North and South Ray Fault. Considering these faults in Tehran and the historical records of the activity of these faults, one day not too far off, Tehran will face a huge earthquake. The historical records of Tehran include such large earthquakes as Damavand (7.1 on the Richter scale) in 2002, Karaj (7.2 on the Richter scale) in 1711, Taleghan (7.7 on the Richter scale) in 958, Ray (7.1 on the Richter scale) in 855, and many other earthquakes above 7 on the Richter scale. However, it is evident that Tehran is not well-prepared to deal with this destructive natural phenomenon (5).

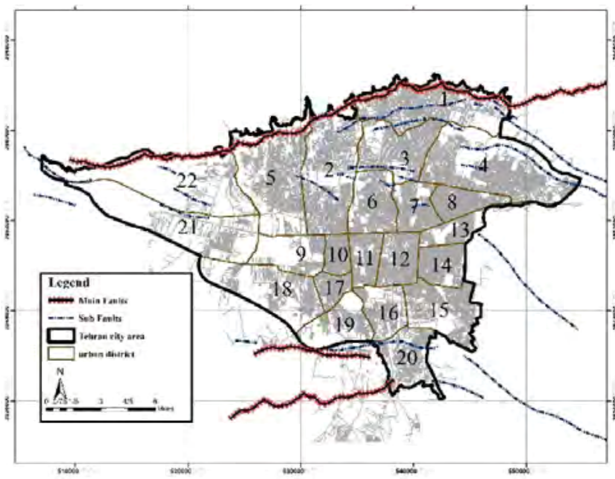

Figure 1. Main and minor faults of Tehran

The central area of Tehran

The central area of Tehran includes Districts 6, 7, 11, 12 (Figure 2). Although this zone encompasses

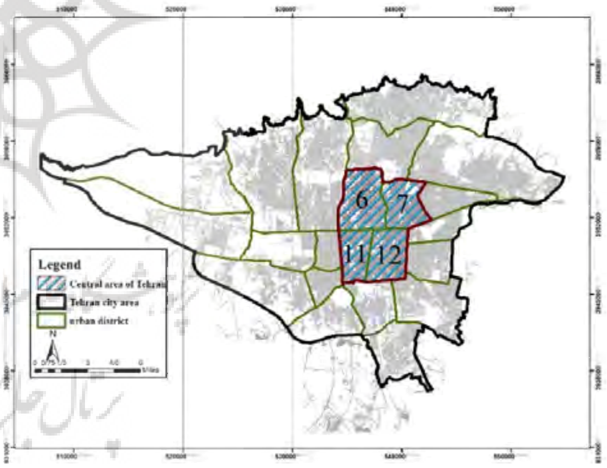

Figure 2. Central area of Tehran city

13% of the population, it is the most crowded area in terms of urban activities and the presence of relief centers (aid-giving centers). As shown in Table 1, the central zone occupies 11% of the Tehran area and accounts for housing 13% of the population. Meanwhile, it includes 95 (65%, out of 146) medical centers and 4 (29%, out of 14) Red Crescent Society centers. Accordingly, it can be concluded that these centers are densely distributed in this zone. The distribution pattern of these centers is illustrated in Figure 3.

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Table 1. Number and percentages of relief centers in the central area of Tehran (source: author)

	Medical centers (N)	Red Crescent Society centers (N)	Crisis management support centers (N)	Population (2017)	Area (square meter)
Central zone	95	4	10	1113349	65075654,45
Tehran	146	14	101	8693706	613573669,6
The ratio of the central zone to Tehran (percentage)	65	29	10	13	11

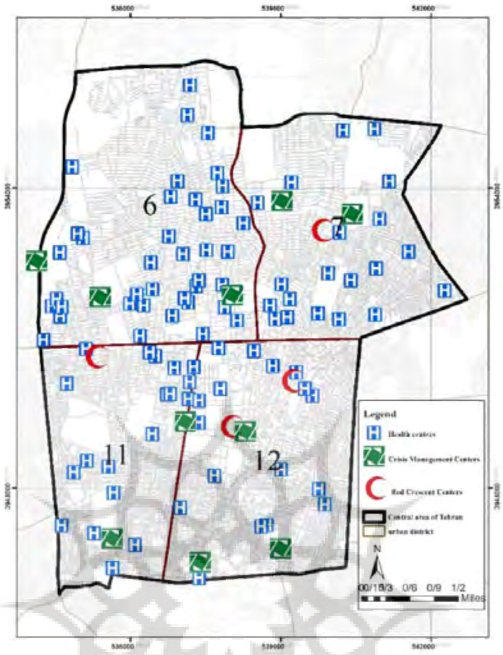

Figure 3. Distribution pattern of the relief centers in the central area of Tehran

Methods

Network analysis method

The basics of network science, which is based on graph theory, should be evaluated initially to analyze the network of relief centers as a coherent whole. As shown in Figure 4, in its simplest form, the network is a set of vertices that are connected in pairs through lines. In graph theory, these points and lines are considered nodes and edges, respectively. Many phenomena in physical, biological, and social sciences can be regarded as networks (19).

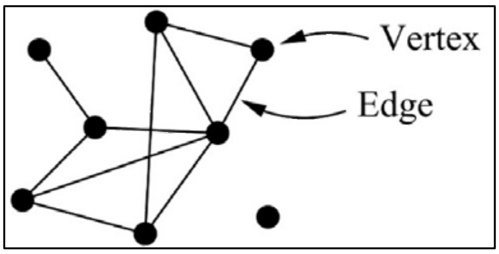

Figure 4. A network with 8 nodes and 10 edges

Networks are critical tools used to describe and analyze the structure and dynamic behavior of several complex systems in the real world (20). Many complex systems, such as power, transportation, and telecommunication can be modeled as a complex network, where nodes represent system components and edges stand for interactions (relationships) between nodes (21). According to the basics of network science, every network has two main components, namely nodes (components) and edges (relationships between them). In this regard, two main components of the network of relief centers should be identified during the modeling process. Considering the definition of the network of relief centers as "A connected set of aid-giving/receiving centers that are attached by rescue routes", the nodes and edges of this network are aid-giving/receiving centers and rescue routes, respectively. Therefore, to model the network of relief centers, the following two steps should be performed.

The modeling process of the network of relief centers is shown in Figure 5.

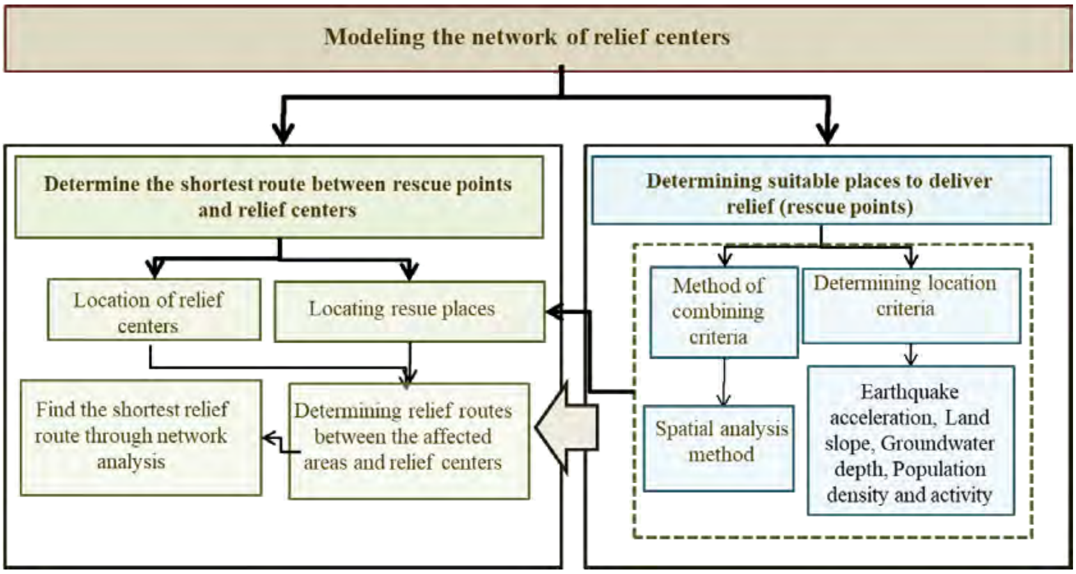

Figure 5. Modeling the network of relief centers

- Determining appropriate locations to deliver aid from rescue centers (aid-giving centers) during an earthquake (aid-receiving points)
- Determining the shortest route between aid-receiving points and aid-giving centers (hospital, Red Crescent center, crisis management support center)

Spatial analysis

Considering that one of the nodes of the relief center (aid-giving) network is the aid-receiving center, it is necessary to locate these points. Proper locations for delivering help from relief centers during an earthquake (aid-receiving points) are places that provide a suitable site for transporting the injured, as well as relief equipment and facilities during an earthquake. Spatial analysis is the method used to locate aid-receiving centers. Accordingly, a brief description of the spatial analysis method is initially presented, followed by its usage in this study.

Spatial analysis has become the dominant paradigm of geography since the 1960s. In the 1980s, the emergence of geographic information systems (GIS) helped strengthen this method. It is worth mentioning that spatial analysis is a crucial component of GIS (22). In a more comprehensive definition, Goodchild (23) introduces spatial analysis as "A set of cartographic skills, as well as mathematical and statistical methods that are used to analyze spatial data".

The spatial analysis aims to describe and argue dispersions in order to create and assess distribution theories. In this method, a place is evaluated based on an objective, one of which is finding location-oriented insights. Accordingly, in order to determine the utilization of a suitable place in an area, the appropriate criteria are initially identified, and then, using spatial analysis, the capacities of that place are evaluated and prioritized (numbered) based on each criterion. Finally, these numbered layers are combined with each other by spatial analysis in GIS resulting in the creation of the final and most suitable place for the desired operation.

According to the aforementioned explanations, in location-oriented activities by spatial analysis, the desired criteria should be identified first. Subsequently, data layers must be entered into GIS and they should be analyzed and integrated by spatial analysis. This study specified the appropriate criteria for determining the right places for receiving aid. Following that, based on these criteria, data layers have been formed in GIS, and then, they have been analyzed and integrated using spatial analysis.

Identification of the criteria for locating aid-receiving points

In terms of safety, aid-receiving points should be well-secured so that they are prone to the most minor damage in an earthquake. In physical-spatial terms, these places should have sufficient accessible open spaces and be well-distributed in such a way as to be accessible from all points of the central zone. In terms of access, these points

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should be reachable to facilitate the relief process. Accordingly, safety, physical, as well as spatial and access criteria can be considered to determine the appropriate location of rescue points. Table 2 summarizes the sub-criteria, necessity, importance, and standard of these criteria.

Table 2. Criteria for determining the right places to deliver aid from relief centers during an earthquake (aid-receiving points)

Criteria	Sub-criteria		The necessity and importance of the criteria	Standard	Reference
Safety	Natural earthquake risk zones	Main faults	In order to reduce the damages caused by the earthquake, aid-receiving centers should be established outside the boundaries considered for the faults in Tehran.	300 meter	24
		Minor faults		200 meter	
	Hazardous types of machinery		In order to prevent the consequences of hazardous uses during an earthquake, such as fire, aid-receiving centers should be as far away from them as possible.	200 meter	25
	Hazardous usage			200 meter	26
	Placement in locations with a suitable slope		Being located on a steep slope causes the earthquake forces to intensify, and as a result, block the routes partially or completely. Therefore, it is necessary to establish aid-receiving centers on lands with suitable slopes	36%	27
Physical/Spatial	Open and green spaces		On the one hand, green and open spaces create suitable conditions for patients, and on the other hand, during an earthquake, they can be suitable places for temporary accommodation of earthquake victims.	100 meter	the author
	Placement in low-density and coarse-grained context with more open space		The placement of aid-receiving centers in low-density areas causes destruction as a result of the collapse of high-rise buildings. Moreover, the low probability of blocking the passages in these contexts makes access to these places easier.		
Access	Distribution in the entire zone of the central region		The aid-receiving centers should be distributed in the central zone in such a way that all regions can access them.		
	Placement across the routes with main accesses		The aid-receiving centers should be established on the main roads so that it is possible to deliver aid to them.		28

Determining the shortest route between aid-receiving and aid-giving centers (hospital, Red Crescent center, crisis management support center)

At this stage, the rescue routes are identified after determining the appropriate places to receive aid during an earthquake. Considering that after the earthquake, aid should be provided from the aid-giving centers to the aid-receiving centers in the shortest possible time, the shortest route between these two places should be identified. One of the common methods to find the shortest path between two points is "network analysis" in the GIS.

Locating the shortest route through network analysis

Network Analyst is one of the prominent programs in GIS. This support tool makes it possible to analyze grid-like geographical phenomena (e.g., streets, highways, rivers, water transmission lines, as well as telephone and power lines). Moreover, it helps analyze more such concepts and places as travel time, the best and shortest route, one-way streets, overpasses and underpasses, and dead-end streets. The other contributions include searching for the principal road route, the most effective ways of transportation, the nearest desired station, or defining service levels based on travel time (29). The analysis of transportation networks is one of the practical fields the most fundamental issue of which is the evaluation of the shortest route. These issues have been under extensive research for many years. The quickest and shortest path is calculated

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as the cost function of the route in the link. Although different studies categorize the shortest path problems, in general, the calculated shortest paths can be distinguished as single-single, single-pair, single, and all-pairs. Software packages solve the shortest path problems in static networks, and the software usually implements all-pairs to all nodes through which the next routes are obtained (30).

- The research procedure and analysis are as follows:
- Collection of spatial and descriptive data
- Preparation and creation of thoroughfare network layers as linear features
- Creation of databases (allowed speed, route length)
- Creation of the location layer of the desired places as point features
- Implementation of topology operations in the software environment (Arc info) to link information to graphic data in the network analysis method
- Identification of the shortest and best route algorithm
- Data analysis in ArcMap software

Findings

After determining the appropriate criteria, the central zone was evaluated based on these criteria. The results are shown in Figure 6, and then, the layers evaluated by the spatial analysis were integrated using GIS, and the right places for relief were located based on all criteria. As shown in Figure 7, 86 points are suitable for receiving aid. According to the considered criteria, these points suffer the least damage during the earthquake, are distributed in all the localities of the central zone, have favorable access, and are established in places where there is sufficient open space.

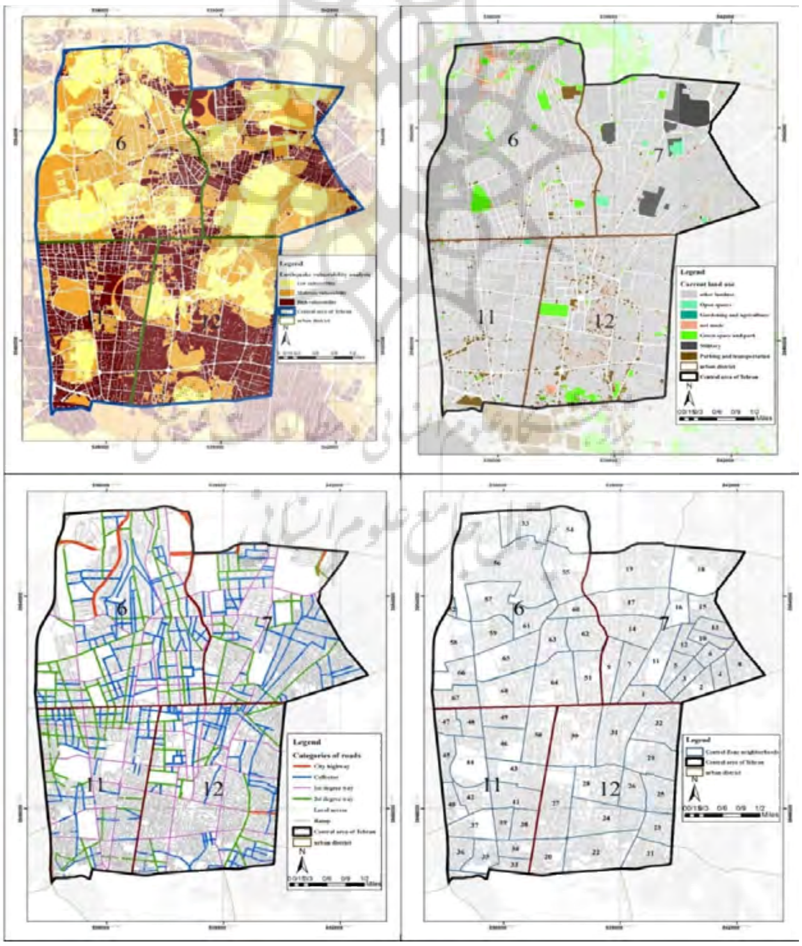

Figure 6. The criteria of the right places for receiving aid during an earthquake

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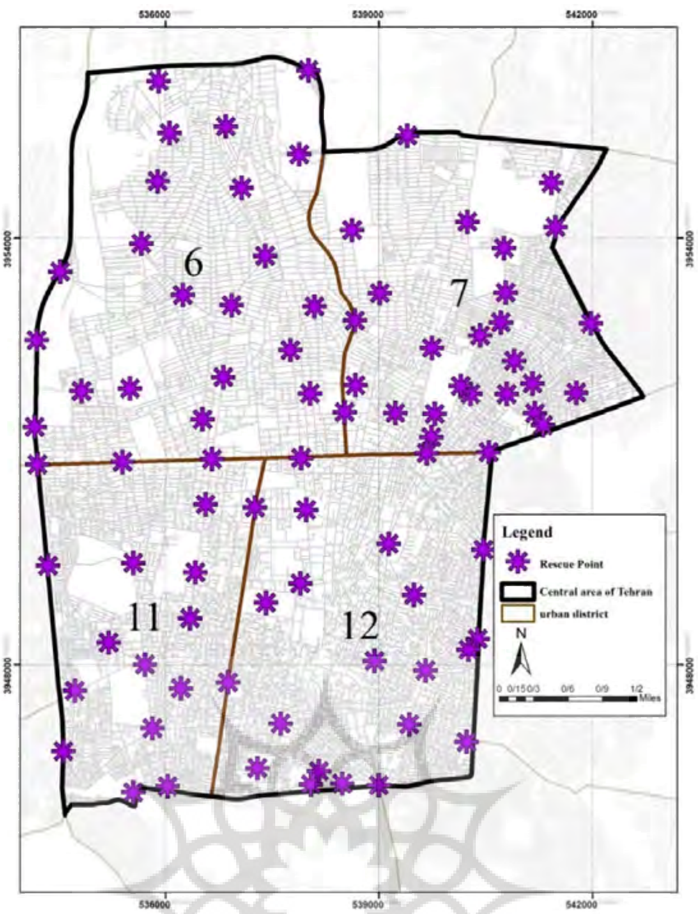

Figure 7. Suitable points for receiving aid during an earthquake

In the next step, the shortest route among medical centers, crisis management support centers, Red Crescent Society centers, and aid-giving locations was calculated using network analysis. As shown in Figure 8, 315 routes are identified for delivering relief. Out of this, 117, 84, and 86 routes were located between aid-receiving points and medical centers, crisis management support centers, as well as Red Crescent Society centers, respectively. These routes deliver relief services from the aid-giving centers to the places where relief is needed in the shortest possible time. Considering that the influence of each element is determined based on its connections and relationships with other elements in a network, at this stage, the relief centers can be analyzed based on the number of relief routes covered by each of them. The relief centers with more relief routes can play a more significant role in post-earthquake conditions. Therefore, these centers can be ranked based on the number of transportation routes. Accordingly, centers in rank one cover the most relief routes and will have the greatest effect during an earthquake. Following that, centers with rank three cover the least relief routes and will have the least effect in this situation.

According to the results, 504, Akbarabadi, Imam Hossein, Andarzgo, and Mehregan hospitals Hasiri Red Crescent center, and crisis management support center 0707 have the most relief routes; accordingly, they play a significant role in providing aid to the central zone. Table 3 tabulates the ranking of these centers. The results obtained from this analysis are given in Figures 8 and 9. Figure 8 illustrates the distribution pattern of relief routes connecting each relief (aid-giving) center to the aid-receiving centers. Moreover, the distribution of crisis management centers and their ranks are shown in Figure 9. Based on this evaluation, hospitals, crisis management support centers, and Red Crescent Society centers, which will have the greatest impact in crisis management after the earthquake in the central zone are ranked one, and those possessing the least impact are ranked three.

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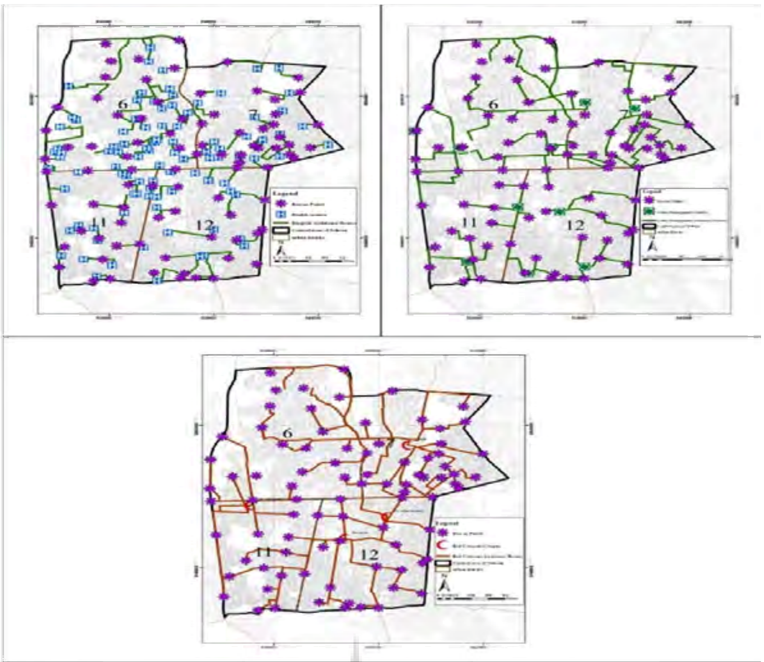

Figure 8. Relief routes of aid-receiving/giving points (hospital, crisis management support center, Red Crescent Society center)

Table 3. Relief center ranking based on the number of relief routes covered

	Hospital	Crisis management support center	Red Crescent center
Rank 1	504, Akbarabadi, Imam Hossein, Andarzgo, Mehregan	0707, 0708, 0601	Hasiri
Rank 2	Akhavan, Ashrafi Esfahani, Baher, Baharlou, Jam, Day, Zahra, Sina, Shariati, Shahrestani, Fahimdeh, Kudakan, Moairi, Namjoo, Nour-al-Zahra, Artesh 502	0602, 1102,1104,1204	Tavasoli
Rank 3	Others	1212, 1213,0218	Khodaverdi, Dehghan

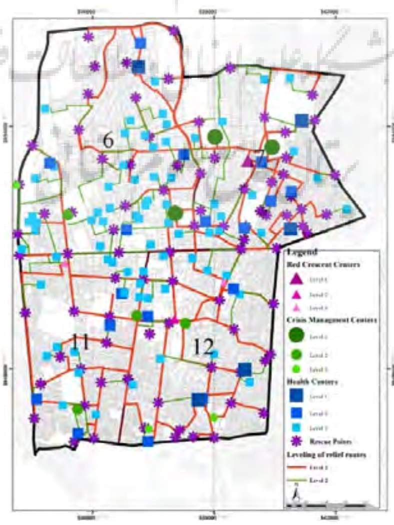

Figure 9. Ranking of relief routes and aid-giving centers

Discussion and Conclusion

As mentioned earlier, due to the high risk of earthquake occurrence, the condition of relief centers is of great importance in Tehran. Although many studies have been conducted on these centers, their evaluations lack a coherent whole and do not include the assessment of the relief routes. Furthermore, these studies evaluated these centers separately without considering their relationships with each other. One of the main studies in this regard is the Seismic Zoning Project of Tehran (JICA). In this study, the vulnerability of relief centers, including hospitals, crisis management support centers, and Red Crescent Society centers has been evaluated during the earthquake, followed by the estimation of the amount of damage caused to them.

In addition to this study, much research has been conducted to evaluate the vulnerability of these centers during an earthquake in Tehran. The results of these studies considering hospitals show that these centers are highly vulnerable to earthquakes. Accordingly, 41% of the hospitals in Tehran are weak in terms of construction quality against earthquakes (7). Furthermore, based on location and neighborhood criteria, 40% of the hospitals are in poor condition during earthquakes (8). It is worth mentioning that there is a dearth of research on crisis management support centers and Red Crescent Society centers. However, the results of a study conducted in 2016 by Ebrahimi et al. show that these centers are not located in suitable places in Tehran (31).

One of the strengths of the present study is the identification of the influence range of these centers during the earthquake considering their connections and relationships with each other and aid-receiving centers during the crisis. Therefore, this novel study made efforts to examine the conditions of these centers in a coherent network and evaluate their influence range in this network. The results of this study initially reveal the right places for receiving aid. The identified locations are safe points that have sufficient open access space, are properly distributed to deliver relief to the entire central zone, and are easily accessible to deliver relief as soon as possible.

As shown in the findings, there is a need for 86 aid-receiving centers in the central area of Tehran that are scattered throughout all regions in this area. These points are of significant importance during an earthquake. The identification of these places makes it possible to equip and prepare them during an earthquake. Therefore, this study recommends regarding these safe points as aid-receiving centers in urban plans to develop necessary programs and arrangements for relief in case of a possible earthquake.

After determining the aid-receiving centers, the rescue routes connecting the rescue points to the aid-receiving centers were identified using network analysis and shortest path analysis (in terms of time) in GIS. Afterward, 315 relief routes have been identified between aid-giving and aid-receiving centers in the central zone. These routes are of great importance since they can deliver the aid needed during an earthquake from the aid-giving centers to the aid-receiving centers in the shortest possible time. The identification of these routes gives urban planners the opportunity to secure them by considering the necessary arrangements for these routes during an earthquake and providing a suitable platform for delivering the relief needed in this situation.

Another result of this section is the ranking of relief routes based on their importance during a crisis. These routes have been identified based on the relief route overlaps among medical centers, crisis management support centers, and Red Crescent Society centers. Therefore, rank-one routes are those that connect a larger number of rescue centers to the aid-receiving points, and as a result, they should be paid special attention. The final results of this study include the ranking of the relief centers based on the number of relief transportation routes to the aid-receiving places. This result is of crucial importance, and this ranking shows the significance of each center based on the relief routes. Accordingly, the centers that have a larger number of relief routes are ranked one, and therefore, are of more importance in providing relief.

As mentioned above, other studies have evaluated the vulnerability of relief centers after an earthquake, and no analysis was allocated to the evaluation of these centers based on the relief routes connecting each center to the ones in need. Accordingly, it can be stated that this study is novel in this regard. According to the results of this study, 504, Akbarabadi, Imam Hossein, Andarzgo, and Mehregan hospitals, crisis management support centers of 0707, 0708, and 0601, as well as Hasiri Red Crescent center were

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ranked one, and as a result, they play a significant role in crisis management during an emergency. The identification of these centers allows the planners to take special measures for these places during earthquakes and provide the necessary planning to improve their performance in this situation.

Acknowledgments

None

Conflict of Interests

The authors declare that they have no conflict of interest.

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