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Evaluation of the Earthquake Resilience of Baghershahr, Iran

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Abstract

INTRODUCTION: Because of the vulnerability of human settlements to natural disasters and damage caused by them, the study of the resilience of settlements has become critical in planning urban areas. The purpose of this study was to evaluate the earthquake resilience of Baghershahr, a town with a population of 67000 people, located at a distance of 4 km from Tehran, Iran.

METHODS: The research data were collected using survey method (questionnaire) and also by using statistical documents and documented reports. The Analytic Hierarchy Process (AHP) technique was used to determine the coefficient of importance of indicators, and descriptive statistics methods were used in data analysis.

FINDINGS: The study area has, on average, only 36.6% of the ideal conditions of resilience. This figure was 25.5% in the institutional dimension, indicating that this dimension has the lowest resilience compared with the other dimensions. The physical dimension has 31.7% of the ideal conditions of resilience, and the economic dimension has 40.5% of the ideal conditions of resilience. The highest level belonged to the social dimension, which was 45.4%.

CONCLUSION: The studied area is an example of Iranian settlements with very low resilience. The low level of resilience of Baghershahr is due to the risks caused by its vicinity to the oil and gas refinery complex, thermal power plant, sulfur industry, and numerous plastic recycling workshops, huge stores of petroleum products, gas and crude oil, and crude oil pipelines. It is also due to sudden formation and uncontrolled rapid growth of the town, which has been accompanied by widespread migration of low-income classes over the past few decades.

Keywords: Hazard; Crisis; Resiliency; Iran

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Introduction

Today, human societies, especially cities, are at risk of more disastrous and deadlier events than the past; 80% of the world's big cities are vulnerable to earthquake and its acute consequences, 60% are threatened by storms and tsunamis, and almost all of them are exposed to adverse effects of climatic variations. The damage caused by disasters in cities exceeded 389 billion dollars in 2011 (1). One of the main issues urban planners are faced with is how to reduce these disasters and their negative consequences. It is evident that the displacement of the population of every vulnerable area, such as seismic belts, is not possible, as most of these areas are among the most suitable areas for living. However, some events can prevent and reduce their adverse impacts, or facilitate or accelerate the return to pre-hazard stable conditions. The attitude towards hazards has changed in recent years; the dominant view has changed from focusing solely on reducing vulnerability to increasing resilience in disasters (2).

The increase in disasters and their resulting financial and human losses required studies on the subject of resilience in social studies (3), and

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subsequently, the concept of "resilience" rapidly expanded in the literature on urban sustainability. Resilience refers to the capability of human habitats to resist and quickly recover from any potential risk. Resilience against crises not only involves decreasing risks and damages, but also includes a return to the previous stable state. The basis and the first step in urban resilience enhancement planning is to evaluate the level of urban resilience (4, 5).

Given the vulnerability of human settlements to natural disasters that occur abundantly and the resulting problems encountered by communities, considerations of resilience in urban planning have become crucial (6). According to the United Nation Office for Disaster Risk Reduction (UNDRR), resilience is the ability of a system or society at risk of a disaster to endure, attract, adapt, and timely and effective retrieval from the impacts of the disaster through the protection and restoration of structures and fundamental and crucial functions (7). Eraydin and Tasan-Kok defined city resilience as "the degree of tolerance for change by cities before reorganization around a new set of structures and processes" (8).

Thus far, the criteria used to evaluate and measure resilience have been vastly discussed (9). Resilience measurement is a novel, but rapidly advancing, field of study and application (10). Banica et al. categorized the earthquake resilience evaluation criteria into the three physical, social, and systemic groups, and specified indices to measure each one. In the physical dimension, risk of vibration, physical properties and state of buildings, life of buildings, number of stories, area of the external walls, insulation of buildings, structural condition of buildings, and landslide potential are considered. In the social dimension, the indices including population density, rate of the elderly population, total residents of the city, and economic losses experienced are examined. Moreover, building density and distance from hospitals and emergency centers are regarded in the systemic dimension (11).

Among the natural hazards, earthquakes are a major threat to human societies, particularly urban communities, due to the large volume of resulting damage and losses and destruction of the structures. It is particularly important since, despite all scientific advances, humankind has not been able to restrain and control the earthquake, or even to delay or anticipate it. In Iran, an average of approximately 200, 20, and 2 earthquakes with magnitudes of, respectively, 4-5, 5-6, and 6-7 Richter are expected and recorded annually, in addition to 2 earthquakes every decade with magnitudes of greater than 7 Richter. Given the length of the active faults of the country and their danger zone (20 km around the faults), 35% of Iran's area is at risk of serious earthquake hazards. Tehran, Iran, is located on 15 small and large faults, with the Rey fault being one of the most dangerous of these faults (12). Since most parts of the country are located on various seismic belts and faults, the assessment of earthquake resilience of the settlements is of substantial importance. In the current study, earthquake resilience of Baghershahr town near Tehran has been evaluated.

Methods

Baghershahr town, 4 km south of Tehran, was the study area in the current study. This region has a surface area of about 44.3 km^2 (Figure 1), and according to the population and house census data of the year 2016, this town has a population of about 67000 people (5).

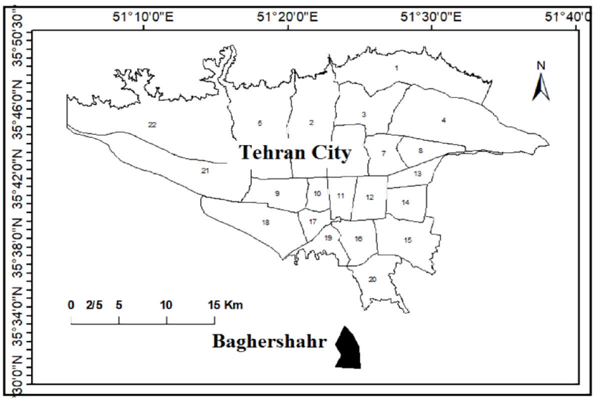

Figure 1. Geographical position of the study area

In this evaluative-analytical study, the data consisted of objective data derived from statistical documents and written reports, and subjective data from the survey. The sample consisted of 374 residents of Baghershahr town. The sample size was determined using Cochran's model and the subjects were randomly selected with the same proportion from different neighborhoods of the town.

The data collection tool was a researcher-made questionnaire with closed questions in which each index was presented as a single item scored on a 5-point scale. Eight experts confirmed the reliability of the questionnaire and its validity was approved with a Cronbach's alpha coefficient of 0.76. Thus, 43 indices were assessed in the four environmental-physical, economic, social, and institutional categories. A part of the indices that included survey data was evaluated by the sample population in 5 ranges, and the evaluation of the documented data in 5 ranges was carried out using opinions of 8 experienced experts and researchers. To do this, the quantity of the study area in each index was declared and they were asked to select the desired range. Then, the average score was considered in the evaluations, and a score of 0 to 8 was considered for each range. Given the non-uniformity of the role of the indices in the resilience of the city, an importance factor was defined for each index using Analytic Hierarchy Process (AHP) technique and using opinions of the 8 experts in the Expert Choice software (Expert Choice Inc., Pittsburgh, PA, USA), and these factors were then turned into a unit ratio. The quantitative evaluation of the resilience of the city was calculated as a percentage of the optimal mode as follows:

$$R = 100 * \frac{\sum(Ei*S*Ci)}{8}$$

In this model, R, Ei, S, and Ci are the earthquake resilience of the city presented as a percentage of the optimal mode. **R:** resilience rate (presented as a percentage of the optimal mode); **Ei:** the value of each index in the range that is specified as a ratio of 1; **S:** the score of each range (0, 2, 4, 6, or 8); and **Ci:** importance factor of each index that is specified as a ratio of 1.

In the optimal situation, each index is in a highly desirable range with a score of 8; therefore, the numerator is divided by 8. The maximum score of the model is 100, which is an ideal state that a city can have in terms of resilience. Naturally, the closer the result is to 100, the more favorable the situation of the city is in terms of the variable or dimension investigated in the model.

Findings

The importance factors calculated for the indices and the final sum of scores derived from each item in importance factors are presented in Table 1.

Table 1. The important factors calculated for the indices and the final sum of scores derived from each item in importance factors

Dimension	Index	Value (for objective indices)	Importance factor	Index score
Physical	Open spaces around residential areas	-	0.0236	0.092
	Presence of peripheral threatening factors (oil storage tanks and pipelines)	-	0.0426	0
	Presence of peripheral threatening industries and plants (oil and gas refining industries - sulfur plant - plastic recycling)	-	0.0426	0
	Peripheral threatening installations (high voltage transmission lines - dams)	-	0.0315	0.099
	Internal threatening factors (fuel stations)	-	0.0283	0.080
	Status of electricity transmission network	-	0.0299	0.102
	Status of passages and intersections in the city	-	0.0347	0.093
	Status of roads connecting the city to peripheral areas	-	0.0252	0.101
	Old and worn out texture	41.4% destruction (14)	0.0389	0.105
	Distance from Kahrizak and Rey faults	3 and 1 km (15)	0.0299	0.029
	Slope and topographic position	1%-plain (15)	0.0174	0.122
	Population density	637 individuals per hectare (16)	0.0299	0.107
	Average residential area	66 m^2 (14)	0.0110	0.012
	Individuals per residential unit	4.88 (14)	0.0174	0.038
	Per capita residential area	13.92 m^2 (14)	0.0126	0.013
	Building density	62.3 to 88.6% (14)	0.0252	0.133
Socio-cultural dimension	Population immutability	-	0.0222	0.074
	Sense of place	-	0.0142	0.064
	Public participation	-	0.0174	0.072
	Social security	-	0.0189	0.074

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Table 1. The important factors calculated for the indices and the final sum of scores derived from each item in importance factors (continue)

Dimension	Index	Value (for objective indices)	Importance factor	Index score
	Religiosity	-	0.0189	0.112
	Family relationships	-	0.0158	0.094
	Neighborhood relationships	-	0.0142	0.070
	Residences' awareness of their city's susceptibility to earthquake	-	0.0205	0.075
	Knowledge of residents about the earthquake	-	0.0299	0.078
	Knowledge of residents about first aids	-	0.0221	0.049
	Awareness of residents of relief agencies	-	0.0173	0.039
	Status of earthquake training courses	-	0.0252	0.042
	Status of earthquake remote training	-	0.0142	0.028
	Percentage of literate people	67% (16)	0.0189	0.101
Economic dimension	Workplace building strength	-	0.0189	0.093
	Insurance of buildings against incidents	-	0.0220	0.015
	Household savings status	-	0.0189	0.025
	Income status	-	0.0173	0.042
	Diversity of occupations in the community	-	0.0157	0.063
	Individuals living in private houses	56.6%	0.0236	0.067
	Employed people	92% of active population (16)	0.0173	0.095
	Dependency ratio	2.3 people (16)	0.0142	0.078
Institutional dimension	Coordination among organizations	-	0.0220	0.052
	People and organizations collaboration	-	0.0189	0.073
	Service performance of the municipality and service providing institutions	-	0.0189	0.054
	Facilities of the relief organizations	(16)	0.0362	0.091
	Facilities for admission and treatment	0	0.0362	0

The sum of the numbers in the index score column for all 43 indices examined was 2.847. With the assumption of ideal (very favorable) conditions, the result will be equal to 8 for all indices:

$$(2.847 \div 8) \times 100 = 35.58$$

Therefore, Baghershahr has only about one-third (35.6%) of the ideal conditions regarding earthquake resilience.

In the physical-environmental dimension, the sum of the 17 scores of indices in the index column was equal to 2.847, and the corresponding sum with the assumption of favorable conditions was equal to 3.6008. Hence, it can be concluded that in this regard, Baghershahr has 31.3% of the ideal conditions regarding earthquake resilience:

$$(1.126 \div 3.6008) \times 100 = 31.27$$

In the social dimension, the sum of the 13 scores of indices in the index column was equal to 0.899, and this sum under conditions in which all the indices were in a very favorable range was equal to 1.198. Hence, it can be concluded that in this regard, Baghershahr has 45.4% of the ideal conditions regarding earthquake resilience:

$$(0.899 \div 1.198) \times 100 = 45.39$$

In the economic dimension, the sum of the 8 scores of indices in the index column was equal to 0.479, and this sum under conditions in which all the indices were in a very favorable range was equal to 1.183. Hence, it can be concluded that in this regard, Baghershahr has 40.5% of the ideal conditions regarding earthquake resilience:

$$(0.479 \div 1.183) \times 100 = 40.45$$

Finally, in the institutional dimension, the sum of the 5 scores of indices in the index column was equal to 0.269, and this sum under conditions in which all the indices were in a very favorable range was equal to 1.058. Hence, it can be concluded that in this regard, Baghershahr has 25.5% of the ideal conditions regarding earthquake resilience:

$$(0.269 \div 1.058) \times 100 = 25.46$$

Conclusion

The present study was conducted with the aim to evaluate the level of earthquake resilience of Baghershahr town. The survey data indicated the low level of income of people living in this city, and that more than 90% of the buildings were not insured against incidents. These factors, in addition to the low level of savings of most families, make it more difficult for the city to recover after the occurrence of disastrous events. Due to the lack of interest in holding courses, earthquake maneuvers, and other forms of training and awareness, there is a low level of awareness of earthquakes and the appropriate behavior in earthquakes among people. Moreover, the level of cooperation of people with organizations or organizations with each other is not desirable. However, family and neighborhood relationships, religiosity, and social participation were relatively strong, which is regarded as a positive component.

In total, Baghershahr benefited from only about one-third (35.6%) of the ideal conditions in terms of earthquake resilience.

In the physical-environmental, social, economic, and institutional dimensions, Baghershahr, respectively, had 31.3%, 45.4%, 40.5%, and 25.5% of the ideal conditions in terms of earthquake resilience.

Given the findings, regarding the economic dimension, Baghershahr exhibited better earthquake resilience, albeit achieving less than half of the ideal conditions. Similarly, the worst situation was observed in the institutional dimension, as only one fourth of the ideal conditions that must be available were realized.

Proximity to faults is one of the potential hazards of earthquake in Baghershahr. This town is located between the two seismic faults of south of Rey (at a distance of 1 km) and Kahrizak (at a 3 km distance). These two faults are among the main and seismic faults of the South of Tehran Province (13). The northern-southern slope of Karaj, Jajroud, and Latian dams towards Baghershahr, as indicated by the riverbeds in the past, along with a small slope (1%) of the city bed, can be a risk factor for city inundation and the occurrence of the phenomenon of liquefaction due to possible earthquake and damage to the upstream dams in Tehran. In terms of relative position, distance from the mountains has protected the city from the risks of landslide and rock falling during earthquakes, but the proximity to the metropolis of Tehran can worsen the problems. Surrounded by the collection of installations and industries, the risk of fire is certain in case of an earthquake in Baghershahr. Oil pipelines transport more than 250 thousand barrels of crude oil (611 liters per second) to this region daily (14). Two gas pipelines with a pressure of 111 pounds per square inch are located around Baghershahr, one leading to the oil refinery plant and the other to the residential areas of Baghershahr. The greater risk is from the tens of huge steel reservoirs, in which millions of liters of fuel and several thousand barrels of crude oil are stored. Due to the long life span of these tanks, even earthquakes with a low magnitude can disrupt some of these reservoirs and cause a fire that can also be transmitted to the rest of the reservoirs. The sulfur production plant also produces hazardous matters that threaten Baghershahr in case of disruption in the reservoirs that is likely in an earthquake. The presence of a petrol station and compressed natural gas (CNG) station in the middle of residential areas and another petrol-CNG station at a distance of several hundred meters from the city are other threatening factors that could cause a massive fire. Every day, about 1,500 oil, fuel, and oil compound tankers (13) are loaded in the area, and often, after passing through the center of Baghershahr, set off to their destinations in Tehran and other cities. Therefore, at any time, on average, at least 625 tankers loaded with a capacity of 25,000 liters have stopped in Baghershahr or are passing at a distance of a few hundred meters of the city, with the risk of fire threatening the city. The presence of a large gas power plant in the south of Baghershahr, and consequently, the presence of high voltage electric posts and cables around the south of the city is another threatening factor.

Per capita passage in the city is 89.9 m^2 (15), which is very low in comparison with other cities in the country. In the current situation, the traffic load of the city is often directed to one main road, which is one of the drawbacks of the road network at a time of crisis. The vast area of old texture (927867 m^2 as 41.5% of the buildings), residents of 50.5% of the households, more than 24% of the population in these areas, and worn out buildings, which comprise 65% of the buildings (16), exacerbate earthquake consequences. Furthermore, about 26.26% of the city area is comprised of empty, abandoned,

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agriculture, and green space land (16), which is a positive component in terms of earthquakes.

The relative density of the population is about 161 people per hectare in the city (16), which is not a very high figure. In the current state of the city, building density varies from 62.3 to 88.6%, and the household density in the residential unit is 1.16 per residential unit (17), indicating that more than one household live in many residential units. Moreover, 83% of residential units are one-story and two-story buildings (17). In addition, the size of residential units is very small; among all residential units of the city, about 10%, 37%, and 57% are less than 50, 70, and 100 m^2, respectively. In addition, 34% and 64% of residential units have 17 area of less than 50 and 70 m^2, respectively (17). Small-sized and large-sized buildings, in combination with the pattern of passages and block size, determine penetrability; in addition, accessibility is a criterion associated with penetrability that is obtained in practice. The small size of parcels allows fewer choices, thus reducing visual and physical penetrability (17). More than half of the buildings in this town (50.2%) are made of mud without skeletal structures (17) susceptible to collapsing with the slightest earthquakes.

Mutability is one of the negative characteristics of the population in Baghershahr. This city embraces numerous immigrants every year from around the country and even from neighboring countries (Afghanistan and Pakistan). Furthermore, every year many of its residents emigrate and settle in Rey or Tehran. Based on the general population and housing census in 2011, 21% of the population of Baghershahr were not settled in Baghershahr in 2006-2011 (17), and are thus considered migrants. Migration is important due to the fact that migrants are less attached to their place of residence, and thus, have a weak sense of place (17); all of these factors can exacerbate the conditions during a crisis. Population consolidation strengthens neighborhood networks, and is effective on the cohesion of the community and the formation and strengthening of cooperation and self-help. Despite the migration attraction, transient population, and the lack of an old and historical background, nearly half of the population of Baghershahr (48.8%) (17) recognize their identity with Baghershahr. Recognition of identity with the place of residence can lead to satisfaction, which creates an attachment to the environment (17).

Although the majority of people in Baghershahr (56.16%) (18) have their own residential property; this rate is lower compared to other cities in Iran. The importance of ownership lies in the owners' higher dedication to repairing, renovating, and maintaining residential texture, and thus, the higher resistance of these textures in crises. Additionally, ownership is effective on population consolidation and stabilization of housing in an area.

Baghershahr lacks a hospital or treatment and admission facilities. The closest and most accessible services of this type are provided in Shohaday-e 7 Tir Hospital of Tehran, located 3.5 km from Baghershahr. Given the limited capacity of the hospital (240 beds) (19), the population density, and the nature of around urban texture, and given that the scope of action of the earthquake is usually wide and the earthquake that affects Baghershahr will probably affect southern Tehran to the same extent, this hospital will be incapable of helping Baghershahr in these circumstances. Of course, access roads to hospitals and treatment centers in Tehran are relatively suitable, but Tehran itself is a metropolis and, in the case of an earthquake, its hospitals will not even be able to accommodate its own population. The relief agencies in Baghershahr are not equipped with adequate facilities. At a regional level, 10 ambulances, 11 tankers, 27 pick-up trucks with different uses, 5 excavators and loaders, 7 dumpers, 10 electricity generators, 10 pumps and sump pumps, 4 air compressors, and 1 clinical bus are the most important relief facilities (19).

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Conflict of Interests

Authors have no conflict of interests.

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