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Evaluating Physical Resilience against Earthquakes in Informal Settlements in District 20 of Tehran

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Original Article

Abstract

INTRODUCTION: In order to increase the capacity to deal with earthquake hazards, increasing urban resilience has become a basic priority for most governments. Based on this, the current research was written with the aim of measuring the physical resilience of the peripheral part of the 20th district of Tehran against earthquakes.

METHODS: The research method is applied in terms of purpose and analytical-exploratory in nature, which was used to analyze information using the AHP technique in Expert Choice software and the opinion of 25 experts.

FINDINGS: The findings showed that district 20 of Tehran city will face a serious crisis due to having many worn-out and marginalized structures, short-term residential units, old buildings, high population density, small area of residential land and narrow roads.

CONCLUSION: According to the obtained results, about 47% of the fabric of district 20 is highly vulnerable to the earthquake crisis. Therefore, appropriate policy-making to manage earthquake crisis, especially in strengthening buildings and land use planning in this area, is an inevitable necessity.

Keywords: District 20 of Tehran; Earthquake; Informal settlements; Physical resilience; Vulnerability

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Introduction

Earthquake has been considered as one of the most catastrophic and destructive types of natural hazards, especially in developing countries (1). The high sensitivity of natural hazards, especially earthquakes, has caused a wide range of activities to be directed to the management of the crisis of hazards in cities, and resilience and thinking about it has become an important concept in scientific research and political discourses (2-4). Iran has one of the worst earthquake vulnerability indicators in the world, which is defined as the amount of damage to property at risk of earthquakes with different powers (5); so that 8% of the most destructive earthquakes occurred in this country (6).

Tehran metropolis, as one of the important cities of Iran, has a high risk of earthquake due to the location of several active faults around and inside it. The seismological history of Tehran shows that the return period of strong earthquakes in urban areas is about 150 years, and the last relatively strong earthquake (M>7) occurred in 1830 (7). The high urban population, building density, in addition to the concentration of resources in Tehran city, increases the complexity of crisis management plans during an earthquake (5). In this regard, the location of district 20 of Tehran in the northern area of Central Iran (Tehran-Ray Plain) due to the operation of several faults in this area, distinguishes this area as the most dangerous area of Tehran from other areas of the city.

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Worn-out structures and marginal areas of this district are more at risk of earthquakes than other structures; these structures are more vulnerable due to non-observance of technical and engineering standards in building construction, placement in sloping lands, inefficient communication network, lack of open and green spaces, lack of urban facilities and equipment. In addition, a large part of the residential areas of the district are composed of fine-grained, impermeable slabs with the use of non-durable and unstable materials, in the event of an earthquake, severe irreparable human and financial damages will be inflicted on the district 20.

Considering the importance of applying the resilience approach to reduce the vulnerability against the earthquake crisis, the current research was written with the aim of measuring the physical resilience of the peripheral part of the 20th district of Tehran metropolis against the earthquake. In line with the purpose of this research, the main question of the research is presented as "what is the physical resilience level of the 20th district of Tehran metropolis from the point of view of vulnerability to earthquakes?"

In the face of accidents, two types of general strategies are proposed: prediction strategy and resilience strategy. The first strategy is used to prepare to face problems and dilemmas, and the second strategy is used to deal with unknown problems (8). Given that natural disasters, especially earthquakes, are unpredictable; by using the second strategy, it is necessary to improve the capacity and ability of residents to resist and deal with disasters (9).

In the field of risk management, resilience is described as the ability of a system or community at risk to resist, absorb, adapt and recover from the effects of a hazard in a timely and efficient manner, including through preservation and restoration (10). Resilience means the ability of a region to face environmental hazards, respond to critical conditions and adapt to it, and quickly and easily return to the conditions after the occurrence of the hazard (11).

Foster (1997) considers the dimensions of resilience to include general, physical, operational, temporal, social, economic and environmental systems (12). Buckle (2006) consider components, such as knowledge of risks, common community values, established social structures (such as communication channels and networks and community organizations), positive social and economic trends, partnership and cooperation between the government and the private sector and social organizations, and finally resources and skills necessary for the resilience of society against danger (13).

Borden et al. (2007) have looked at this issue from a physical-infrastructural point of view, and according to their research, infrastructures and buildings with insufficient endurance, inadequacy of public infrastructure, and industrial and commercial development and growth increase the level of vulnerability of cities to hazards (14). While Mayunga (2007) introduces five types of social, economic, physical, human and natural capital as criteria for evaluating resilient societies (15).

According to Olshansky et al. (2006) since the damage to the network of roads and highways threatens the revival of commercial use and severely reduces economic growth, the reestablishment of transportation is the most important priority to make a society resilient (16).

Colten et al. (2008) consider it vital to pay attention to the body of urban communities that reduce vulnerability and improve resilience against natural hazards, such as earthquakes through the formulation of resistant urban construction standards (17).

Tilio et al. (2011) consider the three aspects of natural structure, resident population and government activities to increase resistance and digest pressures necessary to create a resilient society (18). Longstaff et al. (2010) believe dimensions and indicators of resilience include things, such as ecological, economic, physical infrastructure, urban community and government characteristics (19). Allan and Bryant (2010) emphasize the role of open spaces during earthquakes (20).

Normandin et al. (2011) believe that dimensions and indicators of resilience are such as income; access to water resources; having an emergency situation plan; population growth; energy; insurance coverage; telecommunications; environmental conditions; housing conditions; safety standards and codes; age; education; gender; employment; health; urban planning; community involvement; training; risk assessment (8).

In Table 1, dimensions and indicators of resilience are briefly shown:

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Table 1. Resilience dimensions and indicators (9)

Dimensions	Definition	Indicators
Social	It is obtained from the difference in the social capacity of societies, in showing a positive reaction, adapting to changes and maintaining adaptive behavior and recovering from accidents and it can be promoted through improving communication, risk awareness, preparation, development and implementation of disaster management and insurance plans to help the recovery process.	Awareness, knowledge, skills, attitudes, social networks, community values, integrity-based organizations, local understanding of risk, consultant services, health and well-being, age, accessibility, language, special needs, place attachment, political engagement, religion, social involvement, the desire to maintain cultural norms before and after the disaster.
Economic	The response and adaptation of individuals and communities so as to enable them to reduce the potential damages of an accident, which shows the economic viability of communities.	The severity (amount) of damages, the capacity or ability to compensate for damages and the ability to return to suitable employment and income conditions in the form of income, sources of income, capital, access to financial services, household savings and funds, insurance, reviving economic activities after a disaster, employment, dependence of employment on a special sector.
Institutional	It contains features related to risk reduction, planning and experience of previous disasters. Here, resilience is affected by the capacity of communities to reduce risk, the employment of local people in reducing risk to create organizational links and improve and protect social systems in a society.	Platform, infrastructure, relationships and performance of institutions, physical characteristics of institutions ,such as the number of local institutions, access to information, trained and volunteer forces, laws and regulations, interaction of local institutions with people and institutions, satisfaction with the performance of institutions, accountability, decision-making centers, how to manage or respond to disasters, such as organizational structure, capacity, leadership, training and experience.
Physical	Evaluating community reaction and post-disaster recovery capacity, such as shelters, residential units, health facilities and infrastructure, such as pipelines, roads and their dependence on other infrastructures.	The number of main arteries, pipelines, roads and critical infrastructures, transportation network, land use, shelter capacity, type of housing, materials, building strength, building quality and age, ownership, type of construction, height of buildings, open space of the building, residence, green space, environmental density, accessibility, geographical features (geotechnical features and slope), intensity and repetition of hazards, faults.

Considering the mentioned four dimensions and the topic of the research, this research has been done with an emphasis on the physical dimensions of resilience.

Maleki et al. indicated (2020) that the central region with a value of 0.667 and the western region with a value of 0.500 respectively are in the first and second places, the northern region and Nourabad area with a net flow value of -0.333 are in the third place and the eastern area is in the last place with a net value of -0.500; therefore, it can be said that there is a difference between the districts of Izeh city in terms of social resilience (21).

Taghavi Zavareh et al. (2020) concluded that the structure and urban spaces of the central and eastern parts of the district due to wear and tear, narrow roads, access problems and high population density are more vulnerable than other areas (22). Mohammadi Sarin Dizej & Ahadnejad Roshti (2021) concluded that the level of resilience in the central and southern parts of the

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city is weak and very weak and physical resilience increases in the northern, western and eastern parts of the regions (23).

Jalalian (2021) showed the resilience of Khaksefid neighborhood and informal settlement contexts against environmental crises is in a weak level (24). Janssen and Ostrom (2006) have reviewed international researches, programs and projects in order to investigate the issue of resilience. The results of the research show that the promotion of human and institutional-management dimensions have the greatest impact in the realization of resilient societies (25).

Huang et al. (2021) investigated factors and mechanisms affecting urban resilience in China. The results of the research indicate that the policy-making system is the most important cause and resource allocation is the most important factor influencing the realization of urban resilience in China. Furthermore, appropriate measures in retrofitting and other dimensions are considered essential for urban resilience planning in China (26). Kapucu et al. (2022) stated that resilience as a dynamic process with an interdisciplinary perspective and multilateral partnerships emphasizing on policymaking and governance leads to adaptation to external and internal disturbances and reduction of urban vulnerabilities (27).

Methods

The research method in the present study is applied in terms of purpose and analytical-exploratory in nature.

In order to achieve the goal of the research, in the first step, some important indicators affecting the evaluation process of urban neighborhoods were identified with a comprehensive library review as well as the evaluation of the study results of related foreign and domestic theses and articles.

A total of 5 professors of Islamic Azad University Islamshahr branch and 20 senior and middle managers of the 20th district of Tehran metropolis were examined and selected using the snowball method based on the Delphi method. The indicators obtained after asking the opinion of urban area experts in the 20th district of Tehran metropolis.

At this stage, the indicators were provided to the selected experts in three separate times and they were requested to express their complementary opinions in addition to specifying the degree of importance of each of these indicators. After making the suggested changes and collecting opinions, the previous indicators were corrected and based on the new indicators; they form the second round questionnaire. In the questionnaire, the expert respondents were asked to declare the effectiveness value of each index on the indicators affecting the evaluation of the resilience components of urban neighborhoods in the 20th district of Tehran by choosing one of the available options. These options are according to the research findings.

Finally, the desired indicators were prioritized using AHP hierarchical analysis method in Expert Choice software. In order to determine the validity of the content, the researcher gave the prepared questionnaire to six professors and specialists of the Department of Geography and Planning of Azad University, Islamshahr Branch, and the validity of the questionnaire was confirmed by the opinion of the professors. In addition, the method used to calculate the reliability of the realized questionnaire in this research was Alpha Cronbach's. The overall reliability coefficient of the questionnaire was 0.92, which indicates the high reliability of the research questionnaire. In order to analyze the data, in the ArcGIS environment, for all the main criteria and sub-criteria, the information layer was prepared, and by combining the effective layers in resilience, a general map of the resilience of the marginalized part of the 20th district of Tehran against the earthquake crisis has been extracted.

Findings

Tehran, as one of the most densely populated cities in the world, is located in an active seismic belt, which has many records of destructive earthquakes in the past. Such a place is under serious threat from destructive earthquakes. Based on studies and researches, the amount of casualties and financial losses caused by an earthquake event with a relatively high magnitude in Tehran will be far beyond what is observed in similar cities in developed and at the same time earthquake-prone countries, such as Japan and European countries.

The negative consequences of a large earthquake, especially in urban areas, are so great that they can create deep social, economic and political changes. Vulnerable areas of cities are among the areas that can reduce the negative effects caused by disasters by knowing, zoning, and making the right policies. Therefore, while identifying vulnerable structures, it is necessary to take serious measures to reduce the vulnerability of urban structures against natural disasters.

District 20 of Tehran municipality, due to having a large proportion of worn-out and marginalized structures, short-lasting residential units, old buildings, high population density, small area of residential plots and narrow passages, will face a serious crisis in the event of an earthquake.

In the current research, first of all, the indicators affecting the physical resilience of the marginal and ineffective part of the 20th district of Tehran against the earthquake crisis were obtained using theoretical principles, then to analyze and determine the importance of the criteria and sub-criteria, the Delphi method and expert opinions have been used. These criteria and sub-criteria are presented in Table No. 2.

In the next step, Expert Choice software was used to determine the preference coefficient (importance) of the criteria and analyze the weight of the criteria and sub-criteria in the AHP model, which were weighted by experts. In this model, values and relative importance are measured with pairwise comparisons and with the help of the 1 to 9 spectrum. From the summation of 25 questionnaires that were completed by expert for weighting the criteria and sub-criteria, Table No. 3 was obtained. In addition, in the calculation of the AHP method, it is important to check the degree of compatibility. This amount shows how much you can trust the priorities obtained from the group members or the priorities of the combination tables. In the present study, the consistency rate with an error of 0.07 has been estimated, which indicates the necessary consistency in judgments (Figure 1).

According to Table No. 3, distance from the fault, proximity to dangerous uses and access to service centers are the most important for increasing resilience, and the least important is the slope criterion.

In the following, to prepare a map of the vulnerability of the marginal texture of the 20th district of Tehran metropolis, after the weights of each criterion were calculated using the AHP method, a layer was prepared for each of the criteria in the ArcGIS environment and After fuzzification of the maps, the weight of each criterion was applied to the respective layers through the Raster Calculator command.

After the weighting operation and the preparation of the fuzzy raster layers and applying the weights obtained from the binary table, the Fuzzy Overlay command has been used to combine the layers to produce the final vulnerability map of the study area (Figure 3).

About 5% of the marginal texture of the 20th district of Tehran is in a very high vulnerability zone and about 42.13% is in the high vulnerability zone according to Figure No. 2 and Table No. 3. Therefore, it can be said that about 47% of the texture of this region is highly vulnerable to crises, including earthquakes.

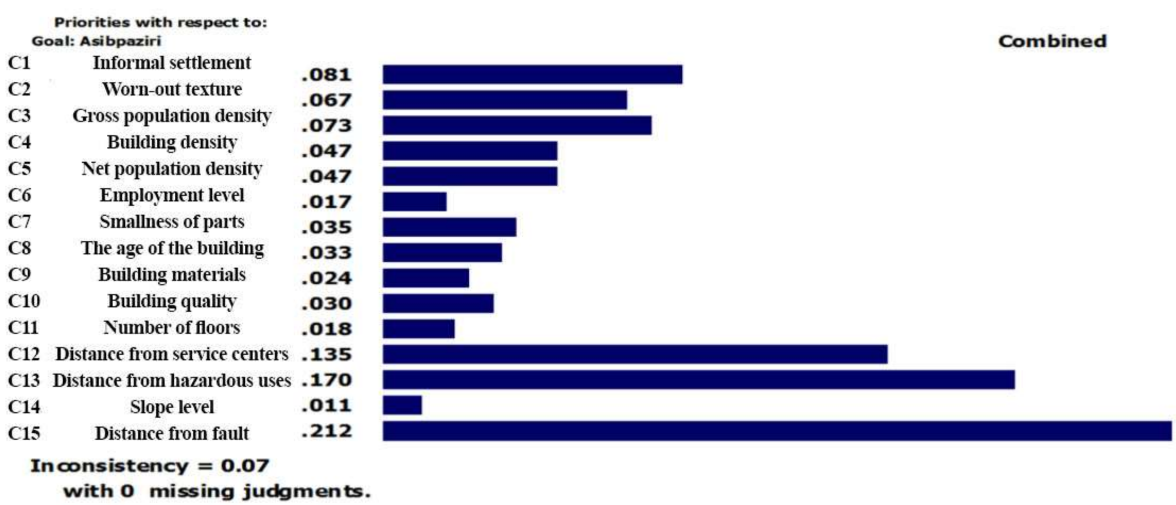

Figure 1. The consistency of the weight of criteria and sub-criteria in the AHP model (Source: research findings, 2023)

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Table 2. Matrix of criteria and sub-criteria and their level of resilience

Criteria	Sub-criteria	Very high 1	high 3	Moderate 5	Low 7	Very low 9
Informal settlement C1	Informal settlement texture					*
Worn-out texture C2	Worn-out texture					*
	Less than 30 people per hectare	*				
	31 to 90 people per hectare		*			
Gross population density C3	91 to 140 people per hectare			*		
	141 to 200 people per hectare				*	
	More than 200 people per hectare					*
	Less than 50 percent	*				
	50 to 100 percent		*			
Building density C4	100 to 150 percent			*		
	150 to 200 percent				*	
	More than 200 percent					*
	Less than 150 people per hectare	*				
	150 to 300 people per hectare		*			
Net population density C5	300 to 400 people per hectare			*		
	400 to 500 people per hectare				*	
	More than 500 people per hectare					*
	0 to 20 percent	*				
	20 to 40 percent		*			
Employment level C6	40 to 60 percent			*		
	60 to 80 percent				*	
	80 to 100 percent					*
	More than 400 square meters	*				
	300 to 400 square meters		*			
Smallness of parts C7	200 to 300 square meters			*		
	100 to 200 square meters				*	
	Less than 100 square meters					*
	Less than 5 years	*				
	50 to 10 years		*			
The age of the building C8	10 to 15 years			*		
	15 to 30 years				*	
	More than 30 years					*
	Concrete skeleton	*				
	Steel structure		*			
Building materials C9	Brick and iron			*		
	Brick and wood				*	
	Clay and mud					*
	Under Construction	*				
	Newly built		*			
Building quality C10	Renovated			*		
	To be demolished				*	
	Ruined					*
	One floor	*				
	Two floor		*			
Number of floors C11	Three floor			*		
	Four floor				*	
	Five floor and more					*
	Less than 250 meters	*				
	250 to 500 meters		*			
Distance from service centers C12	500 to 1000 meters			*		
	1000 to 1500 meters				*	
	More than 1500 meters					*
	More than 1000 meters	*				
	750 to 1000 meters		*			
Distance from hazardous uses C13	500 to 750 meters			*		
	250 to 500 meters				*	
	Less than 250 meters					*
	Less than 5 percent	*				
	5 to 8 percent		*			
Slope level C14	8 to 15 percent			*		
	15 to 25 percent				*	
	More than 25 percent					*
	More than 2000 meters	*				
	1500 to 2000 meters		*			
Distance from fault C15	1000 to 1500 meters			*		
	500 to 1000 meters				*	
	Less than 500 meters					*

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Table 3. Pairwise comparison of criteria

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	Weight
C1	1	3	2	4	2	5	2	2	4	2	2	0.3	0.3	6	0.3	0.081
C2	0.3	1	2	3	2	3	2	2	4	2	5	0.3	0.3	6	0.2	0.067
C3	0.5	0.5	1	4	3	4	3	4	4	2	4	0.3	0.3	6	0.2	0.073
C4	0.3	0.3	0.3	1	2	4	2	2	3	2	3	0.3	0.2	7	0.2	0.047
C5	0.5	0.5	0.5	0.3	1	3	3	3	2	2	5	0.2	0.2	5	0.2	0.047
C6	0.2	0.3	0.3	0.3	0.3	1	0.3	0.3	0.5	0.5	0.5	0.2	0.1	4	0.1	0.017
C7	0.5	0.5	0.3	0.5	0.3	0.3	1	2	2	1	4	0.3	0.2	3	0.2	0.035
C8	0.5	0.5	0.3	0.5	0.3	0.3	0.5	1	3	1	3	0.2	0.2	5	0.2	0.033
C9	0.3	0.3	0.3	0.3	0.5	0.2	0.5	0.3	1	1	2	0.3	0.2	4	0.2	0.024
C10	0.5	0.2	0.3	0.3	0.2	0.2	0.3	0.5	0.3	1	3	0.3	0.2	3	0.2	0.030
C11	0.5	0.2	0.3	0.3	0.2	0.2	0.3	0.3	0.5	0.3	1	3	0.3	0.2	0.1	0.018
C12	3	3	3	4	5	6	4	5	4	4	6	1	0.5	9	0.5	0.135
C13	3	4	4	5	6	7	5	6	6	6	6	0.2	1	5	0.3	0.170
C14	0.2	0.2	0.2	0.1	0.2	0.3	0.3	0.2	0.3	0.3	0.3	0.1	0.2	1	0.1	0.011
C15	4	5	5	6	5	7	5	5	5	6	8	2	3	7	1	0.212

Discussion and Conclusion

Today, cities are considered as the most dynamic residential areas to achieve development, which, despite providing opportunities for socio-economic growth and development, face multiple challenges such as high population density, heavy traffic, lack of housing, lack of resources, reduction of biodiversity, islands Thermal, noise pollution and weather pollution as well as all kinds of human and natural hazards and crises.

In the meantime, continuous crises and hazards such as earthquakes can disrupt the livability and living conditions in cities. Therefore, the concept of resilience has been proposed as an approach to face crises and their effects in the past few decades, and the principles needed to make cities resilient have been presented in several international organizations and discourses.

In the resilience approach, the most important principle is to measure the level of vulnerability and provide solutions to make human settlements resilient. In this regard, the present research has been conducted with the aim of evaluating and measuring the resilience of the marginal texture of the 20th district of Tehran against earthquakes. District 20 is located in the subsidence area of North Central Iran (Tehran-Ray Plain). In the obtained results, 3 criteria of distance from the fault, proximity to dangerous uses and access to service centers were the most important to increase resilience. District 20 is located in the wide subsidence of the north of central Iran (Tehran-Ray Plain). This part, which covers the central and southern parts of Tehran, Shahre-Ray and its south, is covered with young and slightly older alluvial deposits, and the alluvial cones of the Kan, Karaj and Jajrood rivers cover its southern parts. The extent of subsidence of Central Iran (Tehran-Ray plain) due to the operation of several faults includes four physiographic parts of Tehran plain, Ray subsidence, South Ray subsidence and Kahrizak subsidence.

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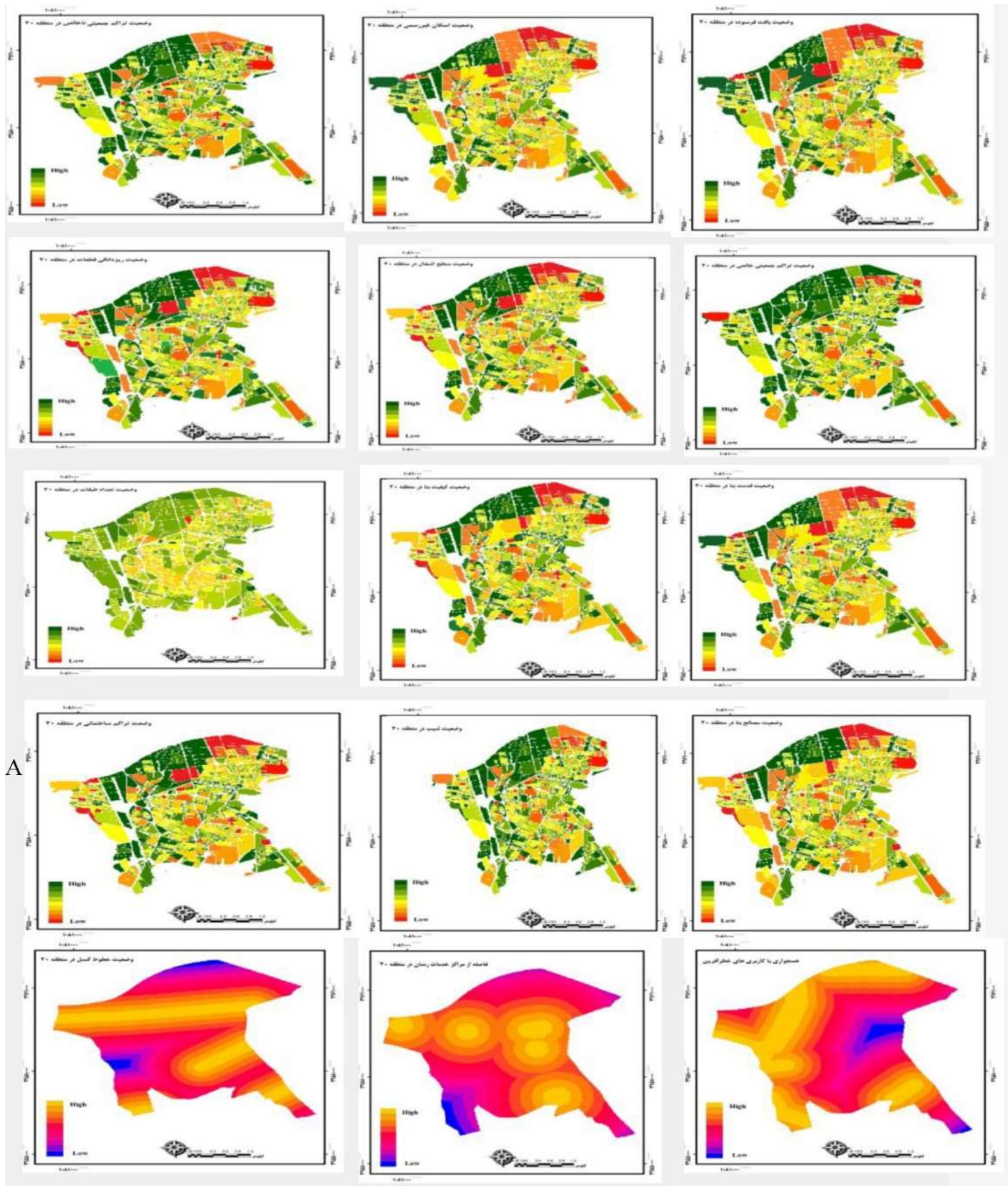

Figure 2. Maps of sub-criteria related to measuring resilience in district 20 of Tehran city

Considering that the maximum length of the South Ray fault and a major part of the North Ray fault are located in the district 20, and the activation of these faults is possible; according to the study conducted by the Japan International Cooperation Agency (JICA), the possibility of three faults being activated in Tehran has been identified, one of which is the South Ray fault. This fault is the most fatal fault in the country and maybe the world if it is active. Furthermore, in this region, the bad location of physical elements and inappropriate urban use, inefficient communication network of the city, compact urban texture, high urban densities, bad location of city infrastructure facilities and the lack and inappropriate distribution of urban open spaces cause a decrease in resilience and an increase in vulnerability in this area.

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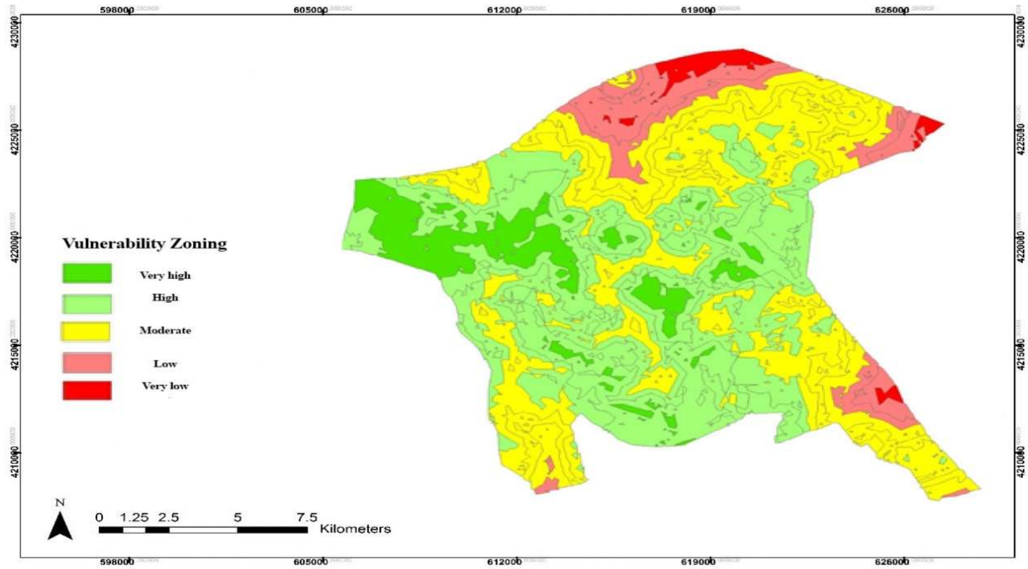

Figure 3. General vulnerability map of the marginal texture of the 20th area of Tehran metropolis against the earthquake crisis resulting from the combination of layers

Table 4. Vulnerability of the marginal texture of the 20th district of Tehran against earthquakes

The degree of vulnerability	area (square meter)	Percent
Very low	131387.1951	2.68
Low	601930.4084	20.17
Moderate	357335.4933	29.12
High	1229520.833	42/13
Very high	286652.0507	5.86

In other words, the reason for the high vulnerability of this region against the earthquake crisis, being in the area of inefficient urban texture (informal settlement and worn-out texture), formation along the main fault of the area, high occupation level, high population density, illegal and unauthorized constructions, impenetrability, construction in unstable lands and other physical characteristics (quality, materials, age and classes) in this area.

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None

Conflict of Interests

The authors have no conflict of interests.

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