Explaining the Model of Urban Resilience to Earthquake According to Natural Site (Case study: Qazvin, Iran)

Javad Poursharifi [a], Manouchehr Tabibian*[b,c], Mohammad Masoud[d,e], Shirin Toghyani[a]

[a] Department of Urban Planning , Najafabad Branch, Islamic Azad University, Najafabad, Iran
[b] Department of Urban Planning, Najafabad Branch, Islamic Azad University, Najafabad, Iran
[c] College of Fine Arts, University of Tehran, Tehran, Iran
[d] Department of Urban Planning, Najafabad Branch, Islamic Azad University, Najafabad, Iran
[e] Department of Urban Planning, Art University, Isfahan, Iran

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Abstract

Cities are among the most fragile life settlements due to their complex internal structure and the influence by different variables. Given the realities of these settlements, in devastating events such as earthquakes, these cities will be definitely more fragile; consequently, returning to normal life seems to be much longer and costly. Given the importance of the issue, in addition to variables taken into account by other researchers in terms of urban structure, this paper has a deeper look at the resilience of cities to earthquakes by considering the conditions of natural sites of cities. It also provides a model of resilience, discusses, and analyzes it in the city of Qazvin, which is located in a high-seismic region with a high relative risk zone. According to the preventive approach to resilience of cities, this program will significantly reduce damages caused by earthquake in the future. In this paper, the algorithm of this model is proposed based on the information obtained from the information analysis on resilience and earthquake, and with regard to the necessity of prioritizing the variables. In fact, this model places a high analytical priority on differentiation of different areas of cities based on natural conditions of their site, and it systematically addresses the issue from the outset. This causes the vulnerability of all parts of the city not to be considered the same under natural conditions and, according to the facts in the natural site, the effect of earthquake on the components of the city are observed, and the critical points are identified. The model output shows that vulnerability in Qazvin is so widespread that the strategy of action during disruption, and returning to initial state are ineffective, and it is better to focus on self-organization and increased pre-earthquake capacity.

***Keywords*:** cities resilience, earthquake, natural site, model, stressors

1. Introduction

Today, for many reasons, including location, inadequate physical development, incompliance with construction regulations, etc., cities around the world are threatened by the damages from natural disasters. Any unexpected natural occurrence resulting in disruption of economic, social, and physical capabilities and destruction of infrastructures, economic resources, and employment is defined as natural disaster including earthquake, flood, drought, seawater level rise, volcano, landslide, and storm (Rezaii, 2010).

Natural disasters around the world have always been considered as a major impediment to sustainable development and, as a result, ways to achieve such development through vulnerability reduction models are favored. Therefore, reducing the risk of disasters is of special importance requiring an appropriate place in natural policies of countries to create favorable conditions for effective risk reduction at different levels (Davis et al, 2005).

Natural hazards have the potential of becoming a disaster in the absence of mechanisms of reduction. Despite the use of predictive tools, future hazards and their state, size, and location cannot be easily predicted based on the evidence. Therefore, increasing or improving the capacity of a system is very important for recovery and resilience to major hazards.

Natural disasters are part of human life and they are increasing in number and variety. Therefore, the focus on merely reduction of vulnerability has changed to the increase of resilience to disasters. Meanwhile, resilience is defined as 1) The extent of damage and destruction a system can bear without breaking the equilibrium, 2) System's ability to self-organize in different conditions, and 3) System's ability to create and increase educational potentials and enhance adaptability to different conditions (Rezaei, 2010).

According to seismic risk zoning plan presented for Iran by Building and Housing Research Center, Qazvin is located in a seismic area with high relative risk (Regulations for Designing Buildings against Earthquakes, 2005). This is due to proximity of Qazvin to the active fault of northern Qazvin with a length of over 60 km and seismicity of 7.2 on Richter scale. The earthquakes occurred in this area over the past decades are strong evidence for the claim. On the other hand, over the past decades, the city has expanded toward northern areas and the active fault of northern Qazvin. Accordingly, in this research, earthquake is considered as an important

*Corresponding author Email address: Tabibian@ut.ac.ir

natural disaster of the area with high probability of occurrence in future. Hence, the main question of this research is: How can a model be used to increase the resilience of cities of Iran in the face of earthquakes?

2. Research Method

In this research, first, through the study of documents, an initial knowledge will be obtained to clarify the situation. Then, research goals and questions are explained coherently, and theories and experiences related to the topic are addressed in line with the goals, through library studies and documents. To discuss theoretical foundations of library studies and descriptive methods, content and comparative content analyses are conducted. Therefore, all the information needed in relation to the resilient city approach, resilient thinking and its dimensions, and the components affecting urban amenity is collected from books, articles, theses and related online sources. The data collected is analyzed descriptively.

In the next step, studies are considered as the basis for development of theoretical framework of the research that supports research hypotheses. Once hypotheses are formulated, using qualitative analysis, research data is assessed and, with the analysis of the relationships between variables, conceptual model of the research is formed. Finally, the principles and criteria obtained are calibrated in line with the research hypothesis, and final criteria and indicators forming the model of city resilience are set. A model with the features mentioned above can be a general guide to achieve city resilience. Therefore, explaining a model for developing the resilient cities and using the indicators considered, in the next step, resilience of Qazvin, as a case, is evaluated and solutions are proposed to improve it.

3. Research Background

Resilience is defined variably, forming many concepts. However, there is a widespread agreement that the essence or the inherent nature of resilience is "back to the past," i.e. “the degree to which the system is capable of bearing risks and organizing itself”. Accordingly, resilience is a combination of "bearing the disorders and returning to the previous state", "self-organization" and "increasing the potential for learning and adaptability". Some studies conducted in this regard are as follows:

In their research, “Urban planning considerations in measuring the vulnerability of cities to earthquakes”, Azizi and Akbari (2008) investigated cities vulnerability to possible earthquakes, using urbanization criteria and AHP and GIS, results of which showed an increase in vulnerability as variables such as slope, population density, construction density, buildings life and distance from open spaces increase. However, increased level of variables such as distance from faults, parcels area, assessment based on width of streets, and compatibility of uses in terms of proximity reduced vulnerability.

Afaridi et al. (2011), in a paper titled "Urban Land Use Assessment with Respect to Earthquake Risk", for the purpose of anticipation of and sustainability to earthquake, evaluated land use and planning strategies for land uses at risk as a long-term approach toward reducing seismic vulnerability, and sustainability in metropolises, and studied District 20 of Tehran as a case. Suggestions were made as a coherent approach for areas with earthquake risk after reviewing, evaluating and analyzing the quality of uses in the area of the case, using GIS, based on planning principles and criteria. RADIUS was also used for seismic risk assessment as well as evaluation of damages. Results of such evaluation have a key role in planning management and urban programs to reduce damages and casualties.

Ferdowsi and Firoozjah (2014) investigated the resilience of urban streets network. In this regard, the research used a descriptive-analytical method to prioritize the organization of streets in order to strengthen their resilience and to reduce their vulnerability to natural hazards, especially earthquake, and evaluated the streets network of the study area (Damghan). Variables considered in their paper included the enclosure, type, length, slope, intersections, and quality of streets paving, rated based on each variable. Finally, based on the set of points and weight of the criteria, all the streets were classified, according to which, the priority for organizing was determined for each street.

Haji Nejad et al (2015) studied five districts of Tabriz in their research titled “Investigating the factors affecting earthquake-caused vulnerability in urban areas using GIS and AHP”. In this research, four variables including population density, building density, quality of buildings, and type of materials were considered. Results showed that, due to high density of population, low quality of buildings, old buildings, and non-resistant materials used in them as well as proximity to fault and slum areas, Districts 1 to 5 of Tabriz are in a very critical condition in terms of vulnerability.

In their research titled "Analysis of Vulnerability Indicators in Old Urban Areas with Earthquake Crisis Management Approach", Mohammadpour et al. (2016), studied the vulnerability of District 12, and Cyrus neighborhood of Tehran. During the analysis, first, values and data of all indicators were obtained, and then relevant indicators were weighted using AHP and Expert Choice. Afterwards, using GIS, vulnerability micro-zoning map was presented in Fuzzy logic. The results showed that highly and very highly vulnerable areas involve more population coverage and, in general, the area was highly vulnerable to earthquake, according to all the physical factors analyzed.

Tilio et al. (2011) in a study titled “Resilient City and Seismic Risk: A Spatial Multi criteria Approach”, examined cities in three aspects: natural structure, inhabitants, and government activities, and suggested the increased tolerance and pressure absorption in each aspect as a factor of increasing resilience. The results showed that a multifaceted approach is required to achieve resilient city.

In their study, "Designing, Planning and Managing Resilient Cities: A Conceptual Structure", Des Sousa and Flannery (2013) considered that ‘to what extent should the cities be resilient? ' and 'how cities, as complex systems, can be resilient?' Creating the potential for resilience, given the massive components, processes, and interactions that occur within physical, logical (law) and virtual (cyberspace) scope of a city and beyond it can be a disturbing job. Planning for resilience to the impact of stressors in cities requires the evaluation of vulnerable components of cities, understanding the processes, procedures, and interactions that regulate these components, and providing the potential for processing various structures of components and their interactions, with the aim of fulfilling the resilience. This article takes a deeper look at resilience in cities, provides a conceptual framework for resilience, discusses, and analyzes it. The framework serves as a holistic approach toward designing, planning, and management of resilience through the assessment of culture and process motives in cities as well as their physical elements.

In the research conducted so far, although in various aspects such as physical, institutional, social, etc., the city's resilience has been addressed, the site of city as a natural bed that covers the city has not been considered and resilience is considered an urban component. On the other hand, in order to achieve a resilient city in the event of crises, the relationship between natural boundary of city and its components is not taken into account as a model and important variables that play different roles in different parts of city are neglected.

4. Theoretical Framework

In general, based on the experiences from earthquakes in the past and the assessment of the extent and distribution of damages caused by them for safety from earthquake hazards, two basic factors including safety of structure and safety of site or structure construction site are considered. Site safety during an earthquake depends on geotechnical and geological hazards such as landslide, liquefaction and intensified ground motion due to the site conditions effect. Site conditions play an important role in the destruction rate of structures. One of the methods of investigating and forecasting to avoid or cope with the above phenomena is the preparation of specific zoning maps containing information about risk potentials. Micro-zoning maps can be used for urban planning, locating important structures and facilities and vital urban arteries, adopting design measures for construction of structures, planning crisis management during earthquakes, or determining resilience of cities prior to earthquakes (Poursharifi, 1997).

PGA is the highest acceleration observed on accelerograph, which is a scale for measuring ground motion intensity (Pouersharifi, 1997).

Due to wide range of definitions and applications of the resilience concept, this paper attempts to identify the most appropriate definition among the existing ones. The best model or framework, which is close to the structural-physical resilience issues, will be selected for subsequent operations. One of the limitations of this study is the lack of a stabilized framework for considering variables. Therefore, by studying and investigating domestic and foreign researches, the most appropriate ones that have a great impact on the degree of structural-physical resilience and are compatible with the physical and natural characteristics of Qazvin city and also be on an urban scale and can determine the result in the field of structural-physical resilience, has been extracted. Based on the results of observations, the urban resilience to earthquake is reported by focusing on the city body includes dimensions and indicators as shown in Table 1.

Table 1
Conceptual model

Concept	Dimensions	Indicators
Earthquake resistance	Environmental	Land type- Distance from fault- Peak ground acceleration (PGA)- Ground slope- Liquefaction
	Buildings	unstable structure –area of buildings – quality of buildings – façade - number of floors
	Function	risky use, population-absorbing use, and lack of access to rescue
	Access	roads width – roads enclosure - risky areas

4.1 Explaining the model of city resilience to earthquakes

After investigating the variables mentioned in relation to earthquake and city, a viable model is obtained. If city resilience to earthquake is the goal of an investigation, then, with a systematic look at the problem, the city should be viewed as a system, the internal components of which have different multi-directional relationships, and the whole system interacts with environment as well. Therefore, two important issues are raised here:

A. Natural site of city: here, the external connection of the system (city) with the outside environment is considered. As stated in Regulation 2800, installation of any facility in the fault zone is strictly prohibited (Building Regulations against

Earthquake, 2005). This means that the natural site where city is located plays a very important role in its resilience. In other words, if the external environment is not acceptable at the beginning, any discussion of system resilience to earthquake will be meaningless.

Of course, variables involved in this area should be treated precisely for a better explanation of consistence of environmental conditions to achieve resilience. In the following, variables involved in this part of the model are clearly described.

B. City components: here, the relationship between subsystems of city main system is considered. Certainly, any subsystem will affect other subsystems due to its features. For example, the height of a building affects the enclosure and function of streets network. In this section, by explaining an appropriate model with regard to components of each district, different solutions can be proposed in order to improve resilience.

Accordingly, the overall structure of the model is presented in Figure 1. As seen in the algorithm, the review process starts from the natural site of city. If there is no natural site, the city is located in an area in which, according to regulations, construction of any building is illegal, and, therefore, the whole process is constrained. However, if the point for city natural site is greater than zero, first, various components of the city are examined, then, according to their points, different solutions are proposed.

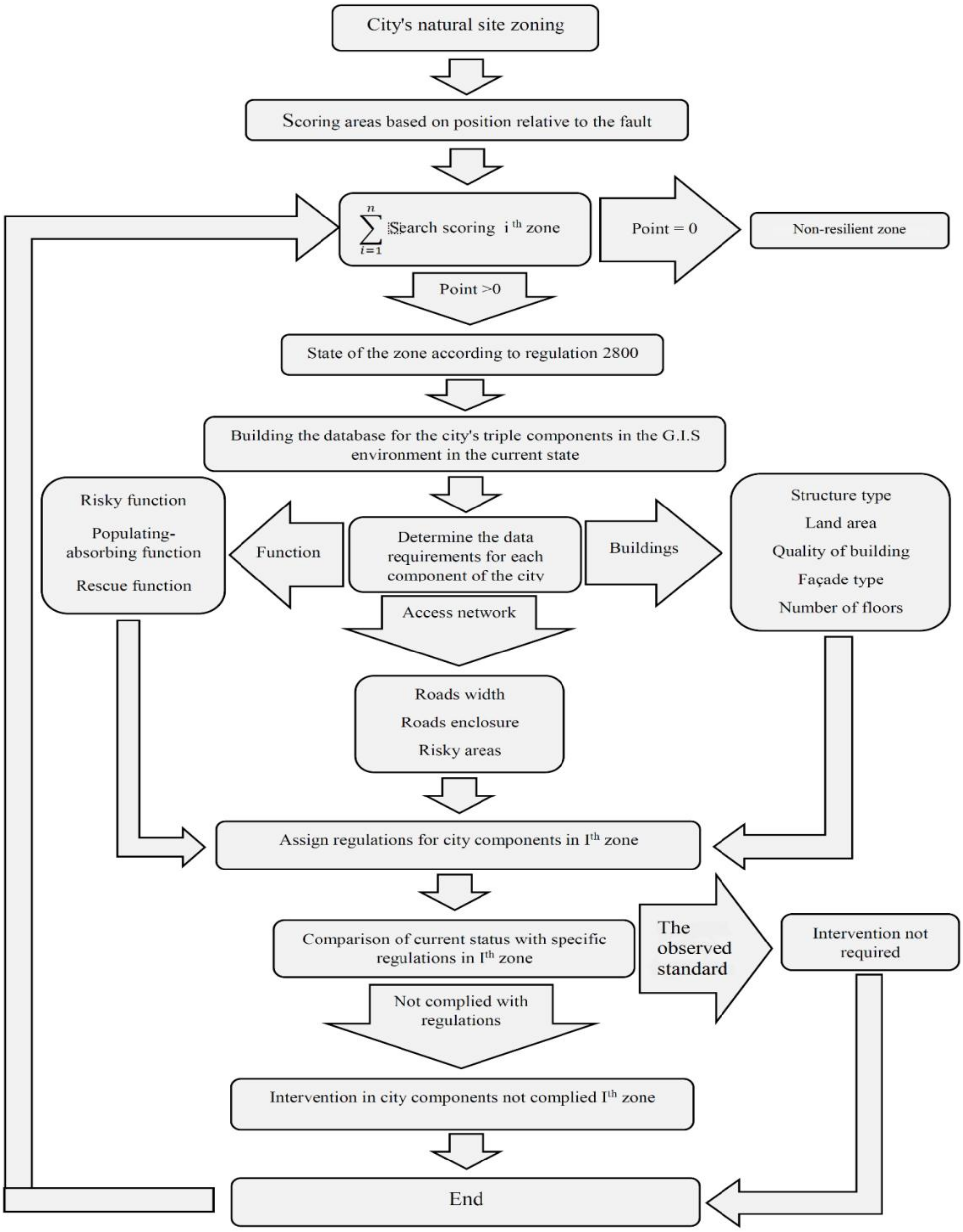

Fig. 1. Algorithm of city resilience to earthquake

4.2 Formulating main variables for the model

As described in the previous sections, variables involved are divided into two parts:
a. Variables affecting natural bed
b. Variables affecting city components (note that due the fact that the city consists of different components, variables of this part are divided into different components).

4.3 Variables affecting natural bed

Although, less attention has been paid to technical conditions of site in urbanism, in the research conducted in civil-earthquake engineering over the past decades in terms of variables affecting seismic magnitude, it has been greatly considered. Jafari and Kamalian (1995) considered topographic and bedding layers. Zare (1993) also considered the effect of soil layers on earthquake waves as a complex process. According to Romanian earthquake information, Jafarzadeh (1990) mentioned a sharp difference between two regions in the acceleration of ground motion due to soil dampening. In a research on Kalamata earthquake in 1986, Harry and Khulafai (1994) referred to the uneven distribution of destructions around the earthquake center. The results stated that alluvial layers in the area around the earthquake center were the most important factor in the destruction of surrounding areas. Poursharifi (1997) considered land type and the distance from fault as factors affecting the extent of damage to buildings.
In Figs. (2) and (3), the city of Qazvin is displayed in terms of these two variables. However, despite the general belief that the greater distance between the faults means the lesser risk of earthquakes, according to studies on seismic micro-zoning in Qazvin, soil type is affected by the intensity of ground acceleration and, as shown in Fig. 4, in areas far from the fault, due to the fine grained soil, the acceleration increased. In other words, environmental conditions are more hazardous now.

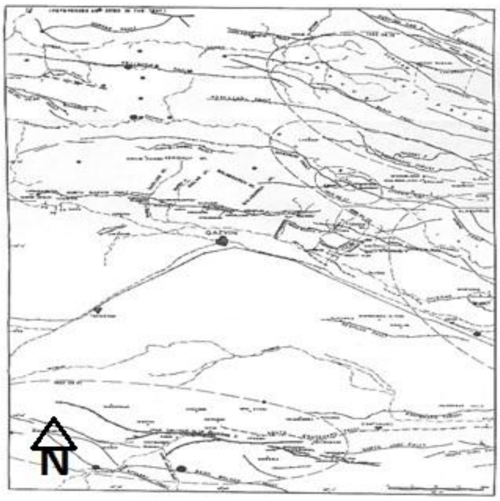

Fig. 2. Location of faults around Qazvin; Source: Berberian et al., 1992

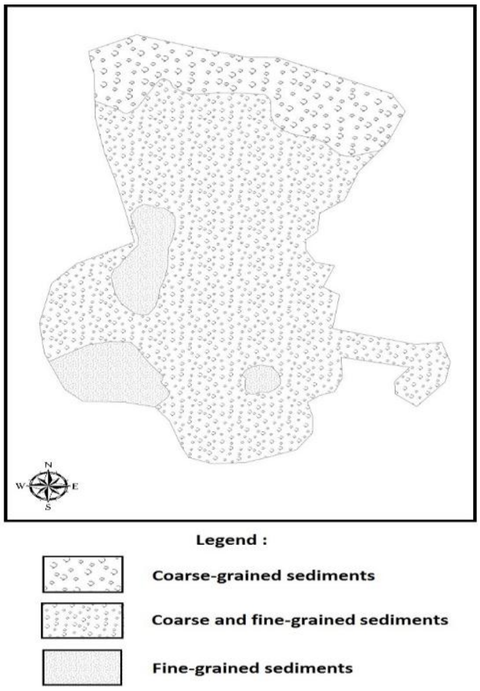

Fig. 3. Distribution of alluvial sediments in Qazvin

Therefore, instead of the two variables, distance from fault and soil type, their effect on natural bed of city is considered as "PGA" (Poursharifi, 1997: 19-37). From the results of previous studies, it is concluded that three variables: Ground slope, Soil liquefaction, and PGA are determinants in this section. For this purpose, the required map is prepared according to the conditions of the case.
Since lack of minimum conditions for each variable causes the natural bed to be non-resistant, in order to take into account the points of these three important variables in the proposed model, multiplication of the points obtained by each variable for each zone is proposed. Lack of points for each variable will make the total point of that zone zero and declare it a non-resilient residence.

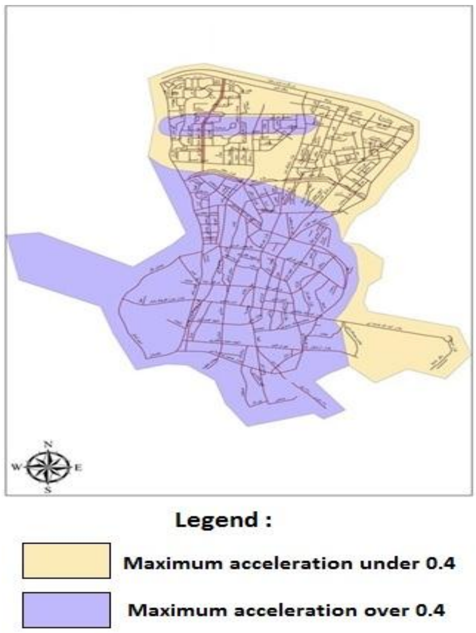

Fig. 4. Zoning PGA in Qazvin

4.4 Variables affecting city components

The structure of a city consists of several subsets, so different classifications have been proposed in different researches. In the present study, city components are classified into three categories: a) Buildings including variables (unstable structure, area of buildings, quality of buildings, façade, and number of floors). This category is affected by earthquake due to its rigidity and it shows different behaviors based on the variables considered for it.

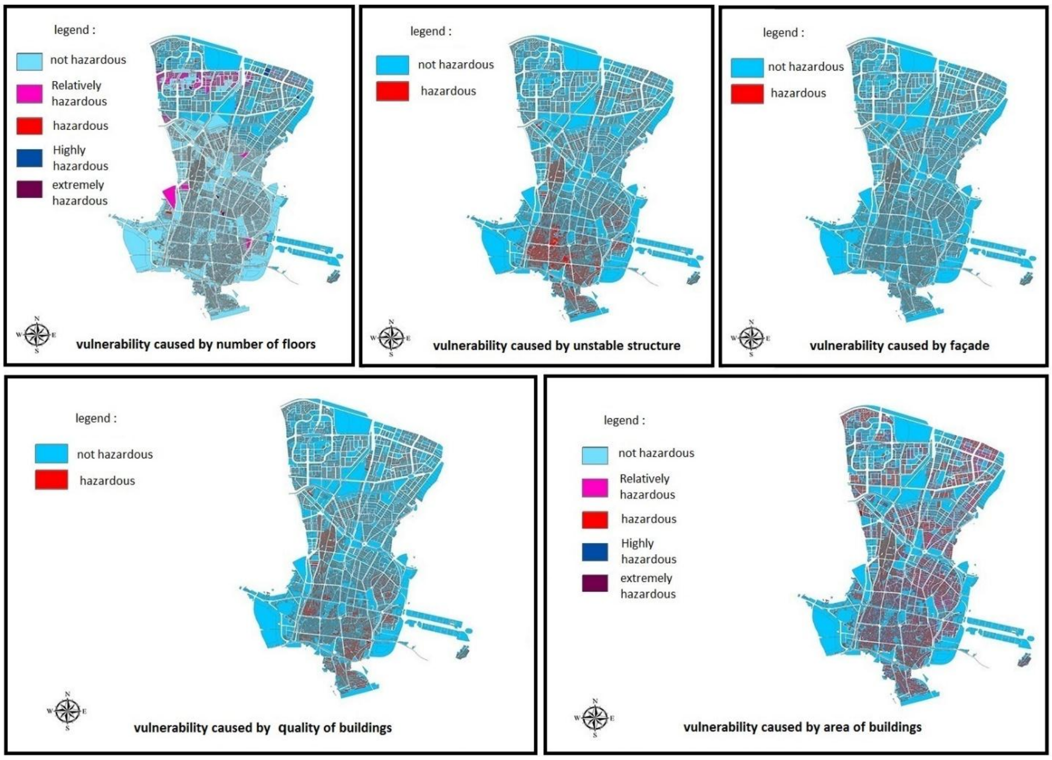

Fig. 5. Buildings database of Qazvin in GIS based on five variables

The overall outcome of these five variables shown in Fig. 4 can better show the overall physical status of the city revealing areas that are more involved during an earthquake. Fig. 6 depicts the superimposition of outcomes presented in Fig. 5.

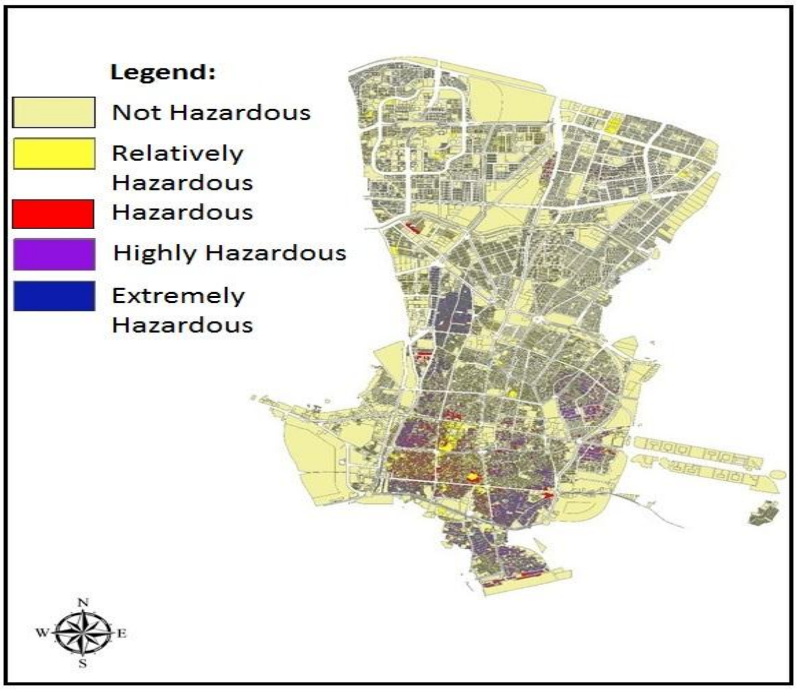

Fig. 6. Outcome of vulnerability status of the city in terms of urban access network

b) Access including variables (roads width, roads enclosure, and risky areas). In discussions about resilience, quick service to return to initial state is mentioned. Access is the aspect that provides this feature of resilience.

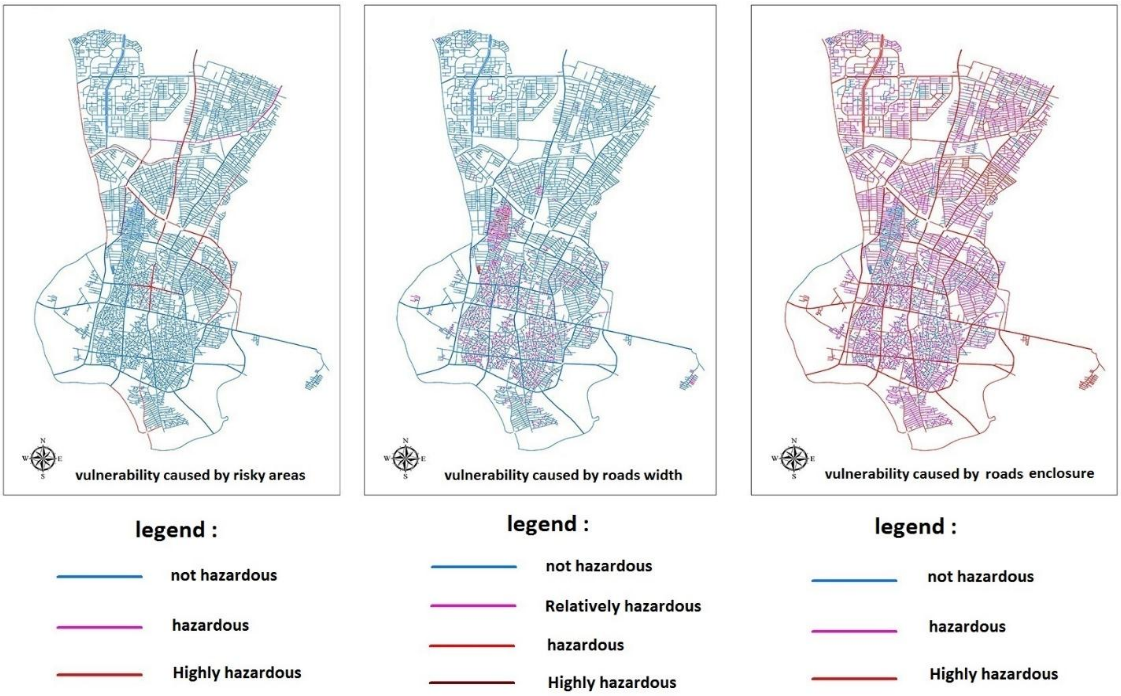

Fig. 7. Access network database of Qazvin in GIS based on three variables

The outcome of three variables that affected resilient of Qazvin roads is depicted in Fig. 7. As it can be seen in the overall status of city roads during an earthquake, primary roads of the city are more vulnerable than secondary roads. Therefore, this issue causes several difficulties for accessing the urban worn-out textures for relief and emergency problems.

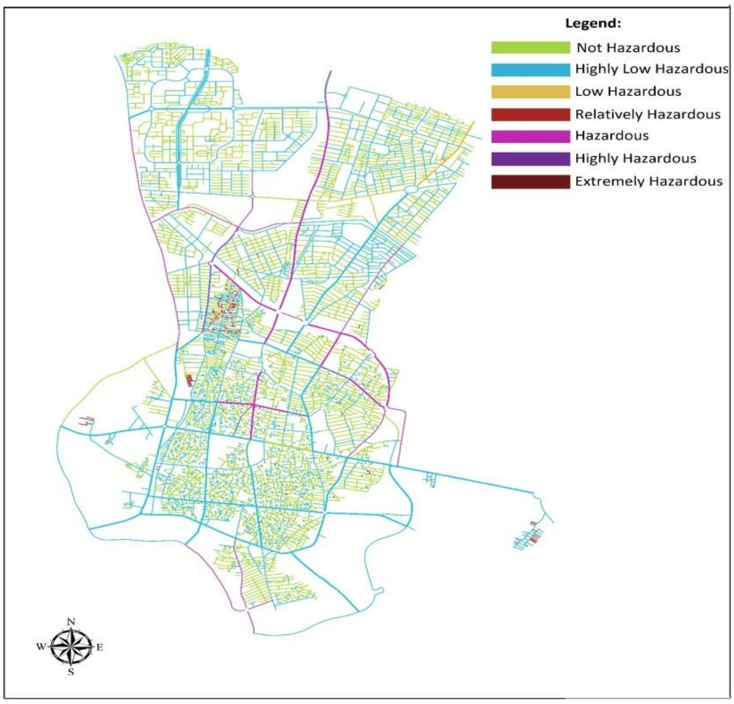

Fig. 8. Consequent of vulnerability status of the city in terms of urban network access

c) Function including variables (risky use, population-absorbing use, and lack of access to rescue). There are various functions in the city. However, some of them are effective in exacerbating or mitigating critical situations. City function covers variables of this aspect of city.

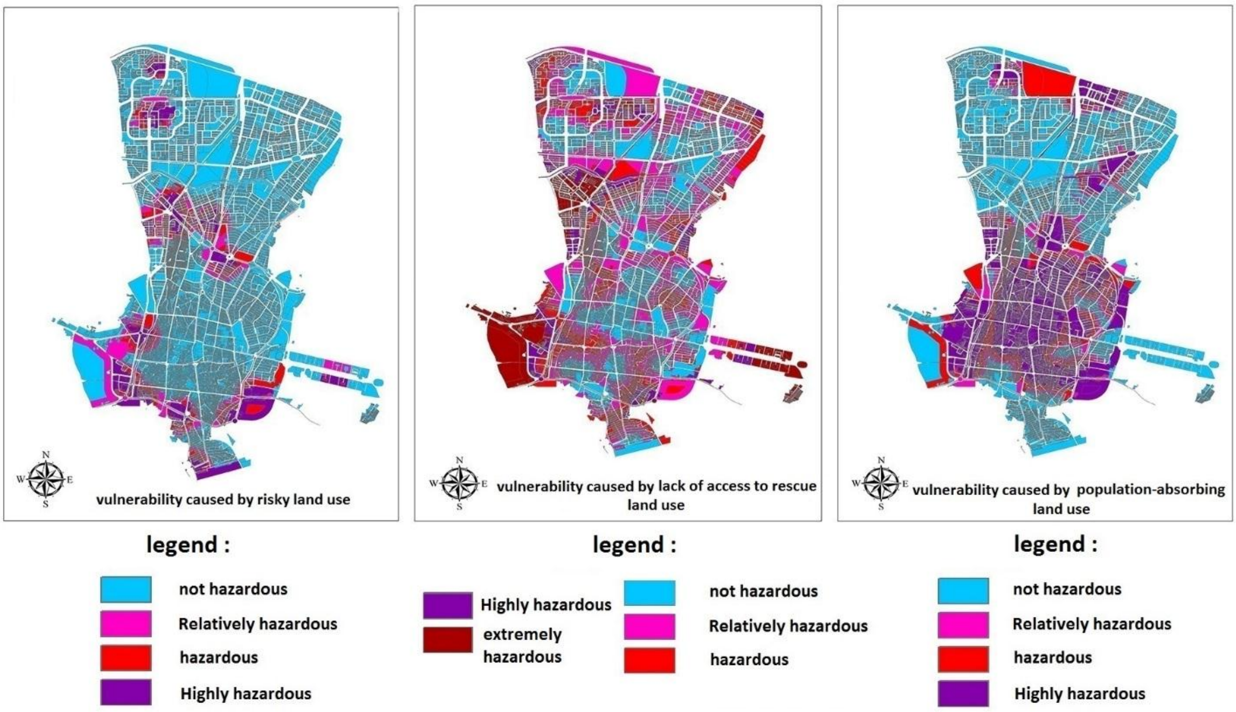

Fig. 9. urban land function database of Qazvin in GIS based on three variables

The outcome of three maps shown in Fig. 8 revealing overall status of urban functions of Qazvin can be seen in Fig. 10. Note that the most troubled urban areas of Qazvin are peripheral ones.

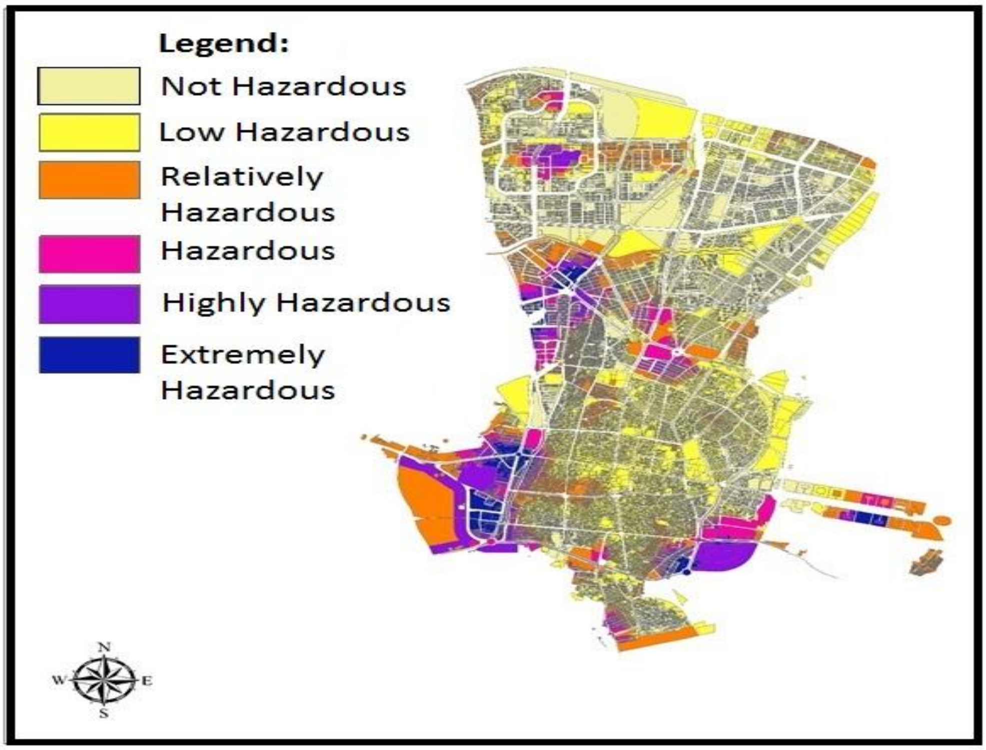

Fig. 10. Consequent of vulnerability status of the city in terms of improper distribution of urban functions

Each city takes different rates depending on its location from previous component. However, natural site of city demands certain requirements to be able to function in all circumstances. The gap between the status of the city and the desired condition that the city is expected to have based on its location, is the gap between the city and its resilience.

5. Conclusion

According to the facts mentioned in the previous sections, the final step in formulation of a model is a precise and systematic arrangement of stages to be taken from the beginning to the end of analysis process. Based on the results obtained from information analysis on resilience and earthquake, and regarding the necessity of prioritizing the variables, the algorithm of this model is proposed in diagram (1).

First, the algorithm begins by examining natural site of the city and zoning it based on site conditions. Next, each zone is analyzed independently based on its dominant natural state. To analyze each zone, the regulations set for its natural state (according to national regulations) are considered as the basis and various components of the city are compared with them. In the event of non-compliance with regulations of variables for each aspect of city components, resolving dilemmas to achieve resilience during crises is required.

In fact, this model places highest priority for analysis on the distinction of different parts of a city, which is natural conditions of their site, and addresses the issue systematically. This has caused the vulnerability of all parts of city not to be the same and, based on the facts in the natural site, the effects of earthquake on city components are noticed and critical points are identified.

The proposed algorithm of this model has the advantage of analyzing each city depending on its geographical extent and its different natural sites. In other words, the general algorithm presented in this model can be used for other cities.

The GIS basis of the model provides us with the ability to consider all variables, and analyze the interaction of variables. The result is displayed in maps in different scales. In addition, due to dynamic nature and variability of cities and their components, the ArcGIS- based database provides the model with easy coordination with daily conditions.

The proposed model opens up the possibility of achieving resilience. Each measure taken throughout the city definitely influences other parts of the city, and a better understanding of this impact requires a model for analyzing these measures.

Using this model, simultaneously with accurate analysis of vulnerability of different parts of the city, makes it possible to identify the disadvantages in access network and rescue operations before earthquakes, and present quick service, providing accurate policies based on the regulations. On the other hand, it is possible to evaluate the effects of these policies on the future of the city and its ability to cope with incidents prior to the implementation of some proposed urban plans, such as increasing the density of a city, and using the model to analyze proposed policies.

In the formulation of regulations, there is a probability that some measures are not taken into account or certain standards are not defined. This model focuses on the issue throughout the analysis process, presented as an algorithm, and if measures are not taken into account in regulations, it allocates a step for extracting these criteria based on experts' views. This is the beginning of the completion of regulations that need to be reviewed.

The model output shows that the vulnerability of Qazvin is so widespread that the strategy of action during disruption, and returning to initial state is ineffective; instead, self-organization and increased pre-earthquake capacity need to be focused. According to GIS maps, more than 75 percent of the city of Qazvin will be vulnerable in physical, functional and access point terms. GIS provides the visibility of city components in current situation, helps identify factors that reduce accountability of city components, and facilitates the continuous assessment of the components of Qazvin to achieve the proposed minimum easily.

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