

## Research Paper

# The Prevalence of Urban Areas Vulnerability to Seismic Risk (A Case Study of Region One, Tehran)

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### Abstract

Urban planning rules and considering land use regarding faults can change the consequences of natural hazard such as earthquake. Vulnerability risk is increasing in Region 1 because of existence of the north fault, steep slopes and continuous construction of high-rise buildings. It is clear that Region 1's Master Plan shouldn't be prepared without considering natural hazard such as earthquake. This study targets two main goals, first, to assess the degree of land use vulnerability to seismic risk and second, to classify areas based on their vulnerability degree. Nine indicators were extracted from previous studies to analyze the vulnerability of land use in Master Plan of Region 1, Tehran. According to different features of each indicator a score from 1 to 4 was allocated for each feature. The vulnerability degree of 181 areas were shown using Categorical Principle Component Analysis (CATPCA) in which areas were divided into four categories and the final result was visualized. The main results of this study showed that more about 50% of the areas were located in the highly-at-risk region. It was concluded that increase in the building density, number of floors, and distance from open spaces would be resulted in higher risk of earthquake damage. The major practical contribution of the present research was that it provided evidence to show that much focus required on reconsidering seismic risk in the future plans.

**Keywords:** Land use planning, Earthquake, Tehran master plan, Tehran's fault.

## 1. INTRODUCTION

One of the most important factors in reducing earthquake damage is awareness to face such phenomenon. This awareness can have several aspects, however, retrofit was what emphasized more among these factors [1]. In 2001, Tehran micro-zoning studies which were published by Japan International Corporation Agency (JICA) mentioned if earthquake happens, injuries would be higher in north of Tehran, and it will cause a dramatic destruction. According to their results, it was prognosticated that 60 per cent of buildings will be destroyed [2]. In general, the main characteristics of the regions at risk were the existence of Tehran north fault and possibility of earthquake, incompatible structure of current buildings, high density of the buildings, lack of open spaces such as parks and green spaces in order to establish aid centers at the time of emergency, impossibility of delivering service because of tourism potentials, construction of housing units on the faults [2].

According to [3-7] urban design and planning can be one of the most effective phase to reduce the vulnerability risk towards earthquake. When a city safety in earthquakes is underscored in all of the urban planning phases, thus the likelihood of risk reduction would be increased. The role of urban design in decreasing or increasing urban vulnerability is significant and how professionals may tackle with earthquake's issue and vulnerability to it can be just as important in reducing the consequences of this natural disaster. Urban Master Plans and their role in seismic risks were highlighted as the major part of urban planning process which could be more related to land use planning of the city [8-13].

As it was mentioned, Master Plans were introduced as one of the solution to reduce vulnerability risk of earthquake damage [14-17]. Indicators related to the role of urban land use planning in seismic risk which were extracted from the previous studies were as follow: land use, land use distribution, building density, development rules such as distance from sites in risk, disproportionate land use proximity, land break down and rules of divining lands, providing required space for different land use [18-21]. Considering these indicators and

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addressing seismic risks in urban planning process can be resulted in the resilience of the regions towards natural hazards such as earthquake [22, 23]. Therefore, the main aim of the current research is to assess the vulnerability degree of the regions to seismic risk based on the above mentioned indicators.

Furthermore, vulnerability risk would increase in Region 1 because of the existence of active north fault, steep slopes and continuous construction of high-rise buildings. It is clear that region 1's Master Plan shouldn't be prepared without considering the natural hazards such as earthquake. Nevertheless, the Master Plans were not the only solution to address this issue, but they could remarkably change the consequences of natural hazard. It is necessary that research and careful assessment specifies which usage and rules should be allocated to the specific lands. This research was trying to answer the following question. What are the prevalence of vulnerability degree of urban areas to seismic risk? This research assessed the vulnerability degree based on the identified indicators from previous studies and also it classified the regions at risk. Accordingly, recommendation and future studies presented to reduce the vulnerability of land use regions towards earthquake.

In a study [24] the planning for the reduction of earthquake damage in the Region 20, the constructional factors, land use, social and economic vulnerability were assessed and their results showed that to what degree earthquake damage may occur in the mentioned region in Tehran. IJCA also in 2001 in a research entitled "seismic micro-zoning in Tehran" considered the Region 22 of Tehran with the aim of preparing micro-zoning plan and they have presented strategies to reduce earthquake risk. JICA's research findings illustrated that there was possibility of activation of three faults in Tehran [2]. They have also indicated the intensity and the number of victims if hazard happens. Another study by [25] using ArcGIS assessed the vulnerability degree in region 17 and a scheme was introduced as a suggestion to reduce the risk based on their results. Another research about urban issues in vulnerability assessment considered the cities vulnerability to earthquake using ArcGIS and AHP method and their results showed that steep slopes, population density, building's density, age of the

building, distance from open space can change the vulnerability [26]. Despite this, increasing in the factors such as distance from faults, accessibility based on pathways width, and land use compatibility in relation to their proximity to each other can cause reduction in the vulnerability degree.

Moreover, [26] in their research of vulnerability factor analysis of residential zones of *Esfahan* in earthquake based on qualitative and quantitative features showed that the high-rise buildings vulnerability to the seismic risk and also poor accessibility conditions for the rescue centers at the time of crisis. Another research assessed the urban land use planning for reducing earthquake injuries with emphasis on the emergency and temporary settlement in *Mahdasht*, Iran [27]. They considered the selection of appropriate location for site preparation for temporary and emergency settlement. Their results elucidated that finding location for rescuing and aid centers could be based on factors including using large areas, scattered rescue and aid centers, safety, applicability, efficiency, and facility. Moreover, [28] in a research assessed the vulnerability of Barcelona city using RISK-UE method indicating the consequences of current hazard to prognosticate the future risks.

With the review of the previous studies it can be said that most of the research assessed the vulnerability and zoning of earthquake risk. Structural indices were more emphasized than urban indices. The gap that this is study attempted to bridge is to show the evidence that related studies should be directly implemented in preparing Master Plans.

## 2. METHODOLOGY

### 2.1. Study area

Region 1 in Tehran was selected as a case study which was consisted of 181 areas (Fig. 1). These areas were categorized as follow: residential area, activities area which is related to work and service, mixed areas which were consisted of residential and other activities, and green and open spaces. Region 1 in Tehran was selected as a case study because of the existence of north fault which was considered hazardous [2].

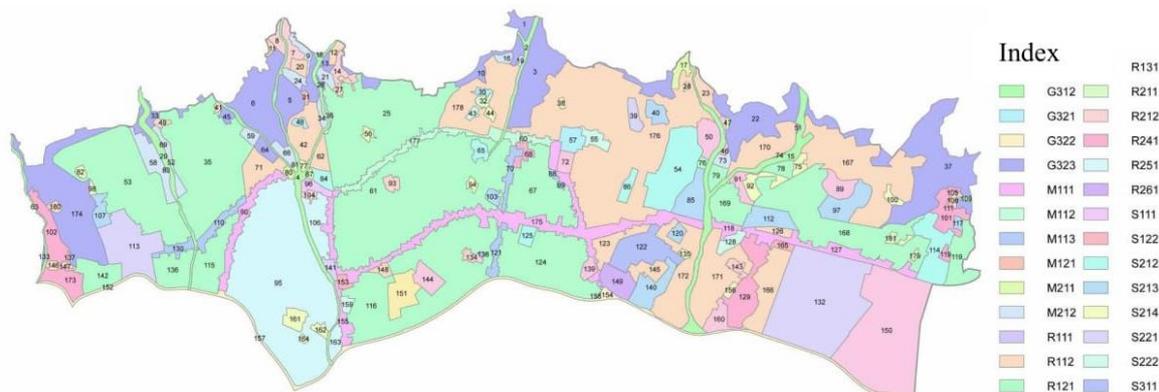


Fig. 1 Study area, Region one, Tehran

## 2.2. Indicators

Nine indicators were extracted from previous studies [1, 3, 24-26] to analyze the vulnerability of land use in Master Plan including: 1) density and area, 2) number of floors, 3) open space accessibility, 4) road network, 5) proximity of land uses, 6) compatibility of land uses, 7) proximity to faults, 8) distance from industrial land use, 9) distance from pylons. A brief description of the above mentioned urban land use indicators which were used in this study explained.

First indicator was “*Area and Density*” which referred to the conditions of land use of the region regarding its open and built areas. It assumed that the more a building has density the more it is vulnerable to earthquake. The “*Number of Floors*” is another indicator which is related to the building’s floors which might be significant in calculation of vulnerability degree. “*Open Space Accessibility*” was one of the most important factors in vulnerability to earthquake. The more open space in the site, the more there was possibility to escape, settling, or even transferring of debris. Therefore, buildings near the open spaces were safer and have less vulnerability. “*Road Network*” could provide the possibility to escape and also aid services, rescue and renovation services [29]. In the Master Plan of Tehran which was completed by Consultancy Engineering of *Bafteshahr* [27], road network and its hierarchy was as follow: i) highways with width of more than 45 meters, ii) Pathways with width of maximum 30 meters, iii) Pathways with maximum width of 20 meters, and finally iv) Distributor and collector pathways with width of 16-20 meters. Land use the network with lower width was more vulnerable because there was possibility for road to be stuck and it would stop the aid or rescue services. Therefore, land use with distance from the road network was more vulnerable. For “*Land adjustment*” it can be said that based on characteristics of the land, vulnerability of the site can be divided into four categories and it will recognize the permitted land use in each site. “*Proximity and adjustment of land uses*” showed the compatibility and incompatibility of the land use with each other. “*Regions location in respect to faults*” that can be calculated based on the area which was defined for each types of fault. In this case, vulnerability can be identified and ranked based on the distance from the fault. This indicator was divided into two main categories including region in 200-500 meter from the fault and the second categories belongs to the areas between 2-5 kilometers from the fault. “*Distance from industrial land use*” in which with increasing the area of industrial land use in the cities and incompatibility of industrial and residential land use urban planners started to distinguish between different land-uses. For several reasons such as transportation,

commute to and from industrial sites and the role of industrial land use in environmental issues their distance with other land use should be considered. Regarding “*Distance from pylons*” it can be said that since electrical equipment and power transformation lines with high voltage has become closer to the residential areas, there was concern of detrimental effects of these sites on human health and increasing diseases. Magnetic waves can affect human health who live nearby, therefore, consideration of their distance to the residential sites can be important in its effects on people’s health.

## 2.3. Data collection

Data related to the indicators were collected from different sources. First, Master Plan of the Region 1 was used to collect data regarding some of the indicators such as density, area, and number of floors. The second part were included the data collected from analysis in ArcGIS including open space accessibility, road network, border of the fault, distance from the fault, distance from industrial land use, distance from pylons (Figs. 2-7).

## 2.4. Data analysis

According to different features (Table 1), all of 181 areas were keyed in using a 4-point likert-scale in IBMSPSS 20. It is required to mention that for each indicator, different scale was used which explained as follow. In the first indicator, “*density and area*” categorization was referenced to a matrix in the study of [25] and the second indicator “*number of floors*” was referenced to the study of [26]. Regarding the “*open space accessibility*”, using Buffer method in ArcGIS, the farthest distance was calculated and divided by four. In the “*Road Network*”, again the farthest distance calculated and was divided by four. “*Land use proximity*” and “*land use compatibility*” was scaled according to a matrix of compatibility and proximity of land use in the study of [5]. And finally, the farthest “*distance to pylons*” and “*distance to industrial land use*” were calculated and divided by four in two last indicators.

The vulnerability degree of 181 areas were calculated using Categorical Principle Component Analysis (CATPCA) in IBMSPSS 20 in which 181 areas were finally divided into four categories and the final result was visualized using ArcGIS. At the end, based on the findings of this study strategies and recommendations were presented. Urban land use planning can be used to reduce vulnerability to earthquake damages and injuries. Location of land use in relation to fault can be important in their level of vulnerability.

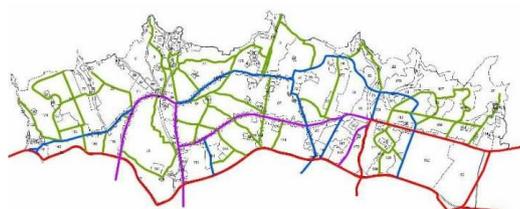


Figure 2: Road network

Grade 1  
Grade 2  
Grade 3  
Grade 4

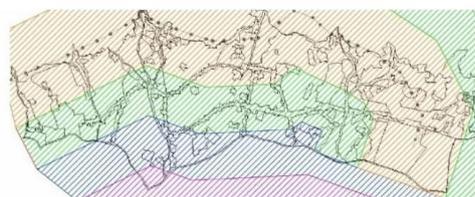


Figure 3: Distance from pylons

<1600 m  
1600-2200 m  
2200-4800 m  
>4800 m

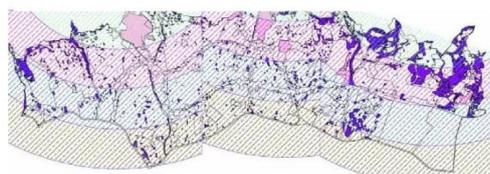


Figure 4: Open space accessibility

Open spaces  
Brown field  
0-1150 m  
1150-2200 m  
2200-2450 m  
2450-2600

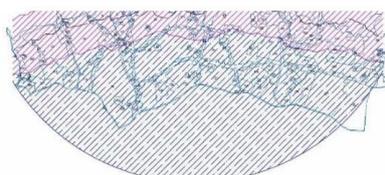


Figure 5: Distance from the fault

Near the fault  
Dangerous zone  
Fault



Figure 6: Border of the fault

150 m from major fault  
200 m from major fault  
100 m from minor fault  
Fault



Figure 7: Distance from industrial land use

Industrial land use  
0-2200 m  
2200-4400 m  
4400-6600 m  
6600-8800 m

Table 1 Degree of land use vulnerability based on different features of nine indicators

Indicators	Vulnerability degree from 1 to 4			
	1	2	3	4
1 Density (area) [25]	0-60% (0-60%) 60-100% (0-70%)	60-100 (70% +) 100-160 (0-70%) 160-240 (0-40%)	100-160(70% +) 160-240 (40-70%) 240+ (0-60%)	160-240(70% +) 240+(60% +)
2 Number of floors [26]	Any number	< 5	> 6	Any number
3 Open space accessibility	<1150 meters distance to the open space	1150-2300 meters distance to the open space	2300-3450 meters distance to the open space	3450-4600 meters distance to the open space
4 Road network	>45 meters width	30-45 meters width	20-30 meters width	<20meters

5	Land use compatibility [5]	Residential in safe sites Activity in safe sites Mixed in safe sites Guarded in all types of sites	Residential in less dangerous sites	Residential in very dangerous sites Activity in less dangerous sites Mixed in less dangerous sites	Residential in less dangerous sites Activity in dangerous and very dangerous sites Mixed in dangerous and very dangerous sites
6	Land use Proximity [5]	R-R* R-G G-G	A-R M-R A-G M-G	A-A A-M M-M	-
7	Distance to the faults' border	Out of the border	In fault	Second border of the fault	First border of the fault
8	Distance to the Industrial land use	<2200 m	2200-4400 m	4400-6600 m	6600-8800 m
9	Distance to the Pylons	< 1600 m	1600-3200 m	3200-4800 m	4800-6400 m

\*R: Residential, M: Mixed, G: Guarded, A: Activity.

### 3. RESULTS

The main aim of this study was to assess the vulnerability degree of 181 areas in Region 1, Tehran. In this study 181 areas of the Region 1 were divided into four categories regarding their vulnerability degree (Fig. 8). The categories included a) not much vulnerable, b) vulnerable, c) very vulnerable and d) very much vulnerable. According to the results, 30% of the areas were located in the not vulnerability region, 18% were located in low vulnerable region, 22% of areas were located in vulnerable region and 28% of the areas were located in very vulnerable region. It was shown that about 50% of the whole area were located in at risk region. The main features of these categories are as follow.

Areas with "not much vulnerability" occupied less than 40% of the area and had above 240% density. Areas that occupied 40-70% area and 160-240 density, and areas with more than 70% area occupation and 100-160% density are also included in the category of the areas with not much vulnerability. The location of these areas are near the fault with any number of floors. However, the width of the road they have assessed to is less than 20 meters. Regarding its land use compatibility, it can be said that residential land use in safe sites, activity-related land use in safe sites, mixed land use in safe sites and guarded land use in all sites all are included in the areas with not much vulnerability degree. In respect to land use proximity, it is observed that residential land use was close to the activity-related type of land use, activity land use to the mixed land use, activity land use to the residential and guarded land use, mixed land use to the mixed and guarded, guarded to the activity and mixed land use. The last feature of these areas is that they are

located out of the faults' border.

Second type of areas which were identified as "vulnerable" have shared features with the first type (not much vulnerable) except for two indicators. Width of the roads in this category is less than 45 meters, and number of floors is only up to five floors.

Thirds type of vulnerable areas which were called "very vulnerable" had also common features with the first two types (not much vulnerable and vulnerable), except for width of the road that is less than 20 meters, and the number of floors in this category is more than six floors for buildings.

Furthermore, features of the last type of areas which were called "very much vulnerable" are as follow. Sub-areas which occupied less than 40% of area and had above 240% density, regions with 40-70% area occupation and 160-240 density, and areas with more than 70% area occupation and 100-160% density are included in the category of the areas with very much vulnerability degree. These are near the fault with any number of floors. However, the width of the road was less than 20 meters. Regarding its land use compatibility, it can be said that residential land use in dangerous sites, activity-related land use and mixed land use in dangerous and very dangerous sites all are included in the regions with very much vulnerability degree. In respect to land use proximity, it is observed that residential land use was close to the activity-related type of land use, activity land use was next to the mixed land use, activity land use was close to the residential and guarded land use, mixed land use to the mixed and guarded, guarded to the activity and mixed. Finally, the last feature is that these areas were located within the first border of the faults that means they are very close to the fault.

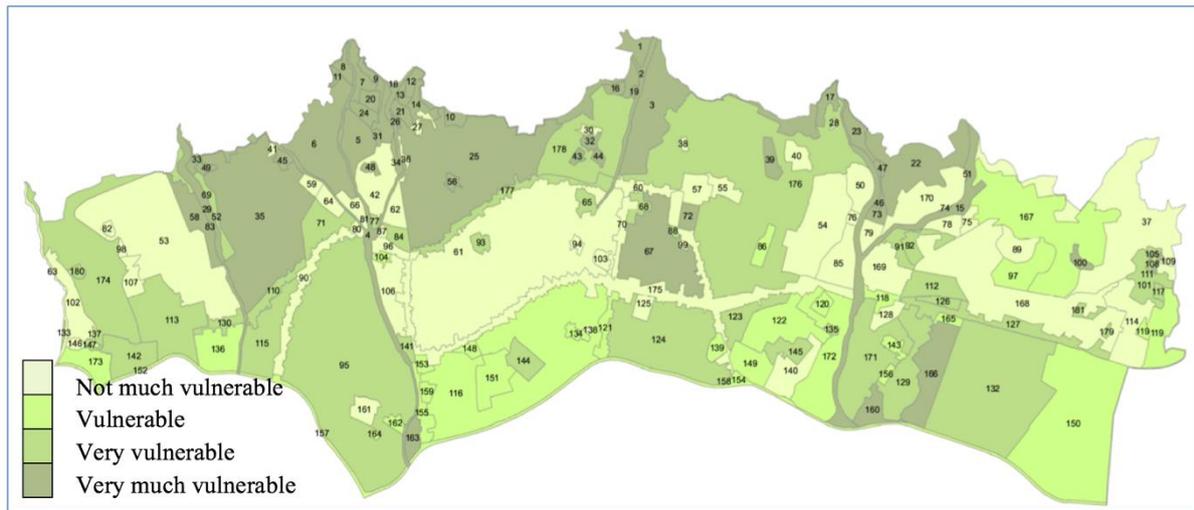


Fig. 8 Land use vulnerability of region 1

#### 4. DISCUSSION AND CONCLUSION

The main results of this study divided the areas in Region 1 of Tehran into four main categories based on their vulnerability degree. There were a number of lands that were recognized as at-high-risk regions. It is shown that unprincipled construction in these regions can have detrimental effects on future of the city and consequently people's life. Strategies regarding the reduction of urban vulnerability level would be: a) crisis policy in which a suitable and appropriate strategy will be taken for emergency aids and also renovation in case if disaster occurs, and b) the reduction policy based on acceptance of the duties and governmental strategies to reduce the risk of natural disaster. In the last strategy structural factors would be divided into four categories to decrease the risk including: coding the buildings, urban land use planning, public awareness and understanding. Urban tools to reduce the risk can be first, legal tools to force people to notice the planning policies in the activities such as land use, insurance, etc. Second, financial tools which is used to encourage people in order to reduce the financial risks. Third, informational tools that is used to present information to people who should be aware of the risk consequences. Forth, motivational tools which is used to encourage people to participate and in using planning policies to reduce earthquake damage including education and public investment [30].

In different land use planning levels, the most effective level is the middle one or urban planning. Direct and indirect assessment of damages is related to the poor conditions of planning process. Moreover, poor planning and lack of urban development rules can be resulted in higher degree of vulnerability [3]. Poor conditions of land use elements and inappropriate land uses, ineffective road network, poor condition of infrastructure and lack and inappropriate distribution of open spaces have the key role in increasing damages of the cities. Remedy of this situation can cause the vulnerabilities of cities to earthquake [1]. In order to decrease the vulnerability of cities to earthquake, land use planning process could be

urged along with standards and urban planning rules earthquake causes should be identified as well [31]. If in specifying land use, proximity indicator was considered, then there would be the possibility of vacating land quickly. Land use which is located in such places that there is no building concentration, urban vulnerability would increase [22].

Logical combination of residential area, industrial, green lands and etc., locating land use base on their distance to faults and also to the scattered centers of cities are examples of logical distribution of land use in reducing the earthquake's victims [32]. Open spaces are the most important land which separate regions at risk from one another [33]. Accessibility to the open spaces and providing a place for temporary settlement at the time of crisis can remarkably help to reduce the number of victims. They have also an essential role to facilitate first aid process, emergency settling down of people and reduce the financial damage [1].

Urban road network has also the substantial role in the degree of vulnerability of a city to earthquake. The preparation of open and appropriate place to escape from danger, accessibility to the safe places, facilitation of first aid, rescue after earthquake, accelerated process of debris cleaning and renovation are some of the factors which are related to the road network availability. In case urban road network was still not damaged and usable after earthquake the number of victims would be less because there is possibility of escape, access to the safe place and also there would be easy movement of aid-related vehicles [8].

Another important factor in increasing the degree of vulnerability is the distance of building from each other. This would shape how land uses adopted and approximated to each other. Each land use has certain efficiency and vulnerability to earthquake and vulnerability will be increased if there is no rule or incompatible land uses were close to each other [29]. In conclusion, urban land use planning is a tool to analyze and describe data about proportionality of development of lands which are at risk of natural disaster. Urban planning can have crucial role to identification of lands and a proper

land use planning provide the possibility to prioritize different activities and operations based on their degree of vulnerability.

This study assessed the vulnerability risk of different areas toward seismic risk and classified them based on the risk. Future study would specifically work on the urban forms in highly-at-risk areas, or the type of land use which are of great benefits in disaster management.

## CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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