ESTIMATION OF SEISMIC RISK IN TEHRAN METROPOLITAN

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ABSTRACT

In this paper a new methodology is presented for comprehensive assessment of the seismic risk in urban areas. In this method, the seismic risk is characterized by definition of physical, human life and socio-economic risk indices. Each of the risk indices are estimated in relative scheme through weighted combination of its sub indicators. Moreover, new hazard factors are defined to make a better interpretation of risk as a combination of the vulnerability and hazard. The response capacity of each urban zone is also measured by indicators of planning, resource, accessibility and evacuation capacity. The overall relative seismic risk index (*RSRi*) is then defined as a function of the three risk indices as well as response capacity index. The proposed method is applied to assess the risk at 22 municipal districts of Tehran in case of North Tehran Fault Scenario Earthquake. The results show that physical and human life risk indices in district 4 of the city are greater than the others. Meanwhile, in socio-economic aspects, district 6 is the highest and district 15 has relatively the maximum overall risk among others. Finally, comparison of the results with JICA study is performed to show the benefits and efficiency of the model.

INTRODUCTION

Similar to all earthquake prone regions in the world, cities of Iran are disposed to seismic threats and experienced earthquakes with large magnitudes in their history (Hessami et al., 2003). Despite the significant development of urban areas in Iran after 1984, still some deficiencies such as population growth, improper occupancy of the land, as well as vulnerability of old buildings, infrastructures, and other urban elements increase the potential consequences of earthquake in Iran cities. These condition, make it essential to perform a comprehensive assessment of risk in Iran's cities to provide an applicable tool for managers and decision makers to allocate their resources for risk mitigation appropriately.

Assessment of the risk is the primary state for any risk reduction and disaster management activities and plans. In other words, usually in urban areas there are no sufficient resources for risk mitigation and retrofitting in various aspects in all urban zones. Therefore, it is important to determine the priorities of risk reduction activities. There have been many studies for developing methodologies for earthquake risk assessment by considering various aspects of hazard and vulnerability, such as, physical, social and economic aspects (Davidson and Shah 1997; Barbat, 2003; Birkmann, 2007; Cardona et al., 2007, 2009; Khazai et al., 2008; Duzgun et al., 2011). In case of Iran, many studies have been performed to assess the seismic vulnerability and risk in urban areas, especially for Tehran (Bahreini, 1998; JICA, 2000, 2004 and 2010; Zebardast, 2007; Ghadiri, 2008; Frughi, 2010; Mansouri, 2010; Ghayamghamian et al., 2011, Motamed et al., 2012). These studies, which performed for Iran's cities and other countries, have some deficiencies for assessment of the risk. Some methods are not comprehensive and some proposed methodologies and parameters, which are local or need a large amount of data for quantification.

Hajibabaee et al. (2013, 2014) presented a new methodology, which has the ability to assess the risk of earthquake in Iran's cities based on relative scheme and by using fewer amounts of data. The method takes into account various hazard, vulnerability and response capacity aspects, through employing a comprehensive set of physical and socio-economic indicators. In this approach, estimation of the risk is performed by combination of vulnerability indicators with their directly-related hazard factors. In addition, the methodology considers the effect of pre- and post- earthquake response capacities. Moreover, the sharing of resources among adjacent urban zones after the earthquake is considered by using expert opinions. Then, Relative Seismic Risk index (RSRi) is defined and calculated through weighted integration of risk and response capacity indicators.

In this paper, the model is introduced and implemented for assessing the risk of Tehran city in case of North Tehran Fault Scenario Earthquake. Moreover, it is tried to compare the results with the results generated by JICA (2000), which is one of the most reliable risk studies for Tehran. For this purpose, in this study, the 1996 census data is used, which was gathered and corrected by TDMMO and JICA Team.

METHODOLOGY

In the proposed method, the earthquake risk at urban areas is characterized by using three main indices of physical, human life and socio-economic risks. Table (1) shows the defined indicators, parameters and their associated weight factors considered to quantify each of the risk indices. The weight factors (w) for each of indicators and indices are determined based on expert opinions by using AHP method.

Since, the vulnerability of physical elements of an urban area (buildings, utility lifelines and transportation systems, etc.) would result to the direct and indirect losses, three indicators of building, utility lifelines and transportation vulnerabilities are proposed to characterize the physical risk. To assess the building risk, urban buildings are classified into eight types (based on their structure) and the risk is estimated by considering structural, non-structural and content losses. Also the urban building occupancies are classified into eight categories in order to estimate the population distribution during three scenario times of earthquake event (2 A.M, 2 P.M, 5 P.M).The casualty indicator is then estimated based on building damage states, casualty rates associated to each building type and the distribution of population in various building types.

The urban lifeline risk is defined by considering water, gas, electricity and tele-communication networks. For estimation of this indicator, the physical damages and physical non-functionalities as well as interaction effects of lifelines on each other, are considered. The risk of transportation network is defined as a separate indicator due to its individual characteristics. The transportation risk is defined as the physical damages of urban roads, which is estimated based on permanent ground deformation (PGD).

The density of building and population as well as preparedness level of people which can significantly affect the evacuation and self-rescue in-time or just after the disaster, are also considered to assess the human life risk index. Furthermore, two indicators are selected for assessment of socio-economic risk condition; social disruption indicator that shows the disorders and violence of people, and household economic condition, that represents the economic resiliency of households.

In this method, the indicators of building, lifelines and transportation risk are estimated by using damage functions and fragility curves. However, indictors of socio-economic risk index as well as density and preparedness indicators are estimated through combination of their associated vulnerability and equivalent hazard factor (EH). This hazard factor is defined based on the probability of building damages and fire ignition. In fact, it is assumed that this factor is the main and direct threat, which can cause the risk and consequences in case of socio-economic and evacuation vulnerabilities. The more description and the method for quantification of each indicator can be found in Hajibabaee et al. (2013) study.

Table 1.Riskindices and their indicators (Hajibabaee et al., 2013)

Index	Sub-components (Indicators)	w
Physical risk (R_{PH}) (w_{PH}=0.30)	R1: Building risk	0.60
	R2: Utility lifeline risk	0.30
	R3: Transportation risk	0.10
Human life risk (R_{HL}) (w_{HL}=0.50)	R4: Casualty potential	0.75
	R5: Density	0.15
	R6: Unpreparedness (of people)	0.10
Socio-economic risk (R_{SE}) (w_{SE}=0.20)	R7: Social disruption potential	0.50
	R8: Household's economic condition	0.50

Furthermore, in this method the capacity for response and management of the risk is defined by response capacity index. This index includes the planning, recourse, accessibility, and evacuation condition for risk management and response activities. Also the post-earthquake reduction of response capacity due to earthquake damages is measured by means of reduction factors. Moreover, sharing of the resources among adjacent urban zones is considered in estimation of the capacity of each urban zone. Table (2) represents the indicators, their components and weight factors considered for assessment of the response capacity index. The approach for quantification of these indicators is described by Hajibabaee et al. (2014).

Table 2. Response capacity indicators (Hajibabaee et al., 2014)

Index	Sub-components (Indicators)	w	Sub-indicators	w
Response capacity (Rc)	C1:Planning Indicator (Rc_P)	0.25	Adequacy level of plan(s)	0.50
			Implementation level of plan(s)	0.50
	C2:Resource Indicator (Rc_R)	0.35	Available financial resources	0.30
			Equipment and facilities	0.35
			Trained manpower	0.35
	C3:Accessibility Indicator (Rc_A)	0.20	Road physical damage	0.30
			Road blockage	0.70
	C4:Evacuation Capacity Indicator (Rc_E)	0.20	Regional evacuation capacity	0.50
			Community evacuation capacity	0.50

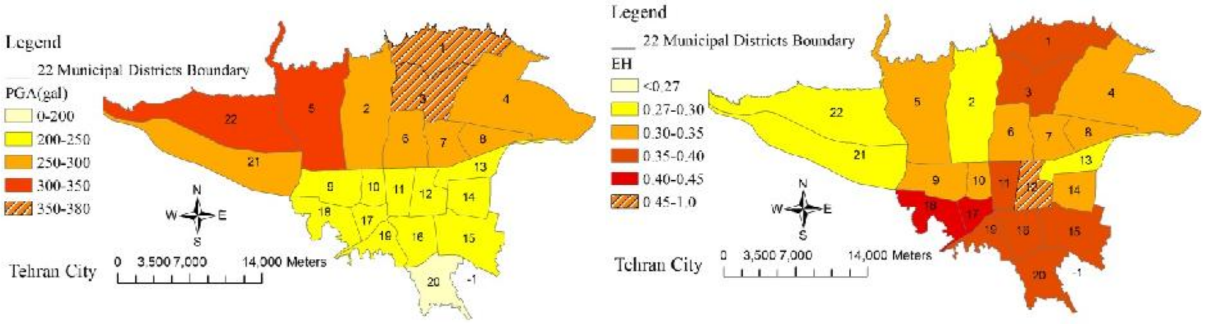
Finally, the total seismic risk index (*RSRi*) is defined by equation (1) as a combination of the risk and response capacity indices.

$$RSRi = \frac{w_{PH}R_{PH} + w_{HL}R_{HL} + w_{SE}R_{SE}}{1.0 + Ln(Rc)} \quad (1)$$

The mathematical relations for assessing each of the risk and response capacity indicators are formulated somehow to estimate the relative quantities instead of the obsolete ones. The relative scheme helps to compare the risk among urban zones at arbitrary scales (neighborhood to district/town levels) without having the result of absolute risk assessments. It also permits the application of simple and indirect techniques for simple quantification of the indicators. In this method, the values estimated for each indicator is normalized by means of ‘mean minus two standard deviation method’, which usually generates the normalized values between 0 and 4.0. Therefore, the *RSRi* as a compound index represents the relative risk of the earthquake among under study urban zones. This index can be used to determine the relative condition of the risk. Also, the contribution of each indicator in total *RSRi* value of each zone can be revealed to inform the city managers and decision makers about the priorities of risk mitigation activities

IMPLEMENTATION

In this paper, the presented method is implemented to assess the risk in 22 municipal districts of Tehran in case of North Tehran Fault Scenario Earthquake. As a result, the relative risk and the effect of each indicator in estimated value of *RSRi* at each zone can be revealed. Such results have a significant role in determination of priority activities for risk mitigation. The distribution of peak ground acceleration for this scenario is presented in Figure (1a) based on JICA (2000) studies. Figure (1b) shows the measured values for equivalent hazard factor (*EH*) in different districts of the city. As illustrated, the PGA value in northern districts especially districts 1 and 3 is higher than other ones. However, *EH* which represents the threats of building damages and fire ignition is higher in some southern districts.

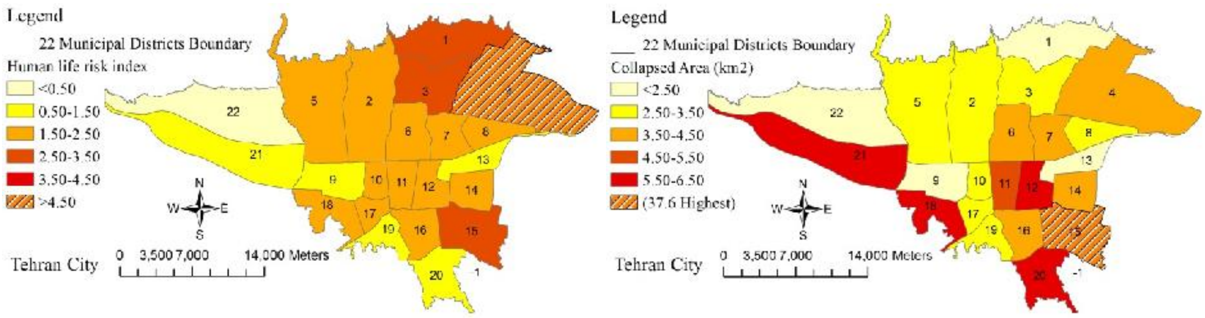


(a) **(b)**

Figure 1. Values of (a) *PGA*, (b) *EH*, at districts of Tehran, North Tehran Fault Scenario Earthquake

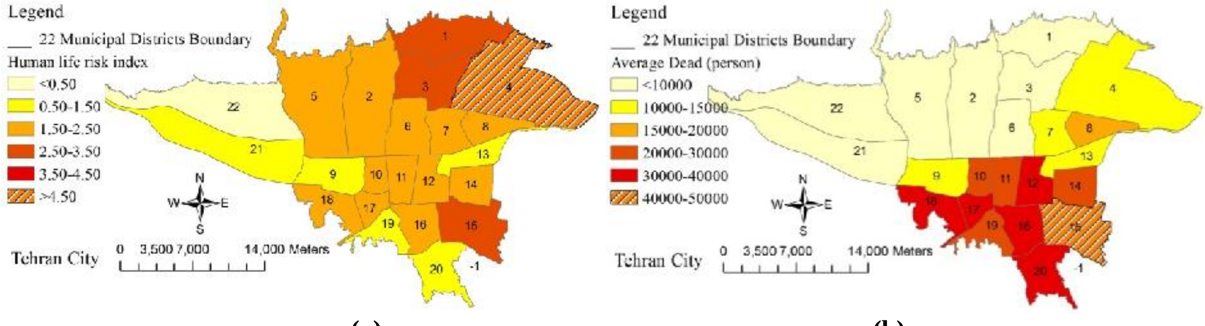
The estimated normalized values of physical, human life and socio-economic risk indices as well as response capacity index at different districts are presented in Figs. 2 to 4. As shown, the physical and human life risk indices in district 4 of the city are greater than the others. On the other hand, districts 6 have the highest risk in socio-economic aspect. Also from Figure (4b), it can be concluded that the capacity of response in northern districts especially districts 2 and 4 is higher than northern ones. The estimated value of the total relative seismic risk index (*RSRi*) in different districts of the city is displayed in Figure (5). As illustrated, districts 15 and 17 have relatively the highest overall risk, districts 4 and 12 are in next position and the relative risk of districts 2, 6, 13 and 22 is the lowest.

Figure (2b) depicts the built floor area of buildings, which would be completely collapsed during the earthquake. Figure (3a) shows the average number of dead persons for three scenario time of earthquake. As illustrated, district 15 has the most quantity in both figures. These consequences as well as having high socio-economic risk and low response capacity at this district are the main causes for being placed on the first step of total relative risk (*RSRi*). Also, in district 4 despite having a relatively high potential for response and management, risk indicators and *RSRi* are high due to large amount of hazard and high level of vulnerability.



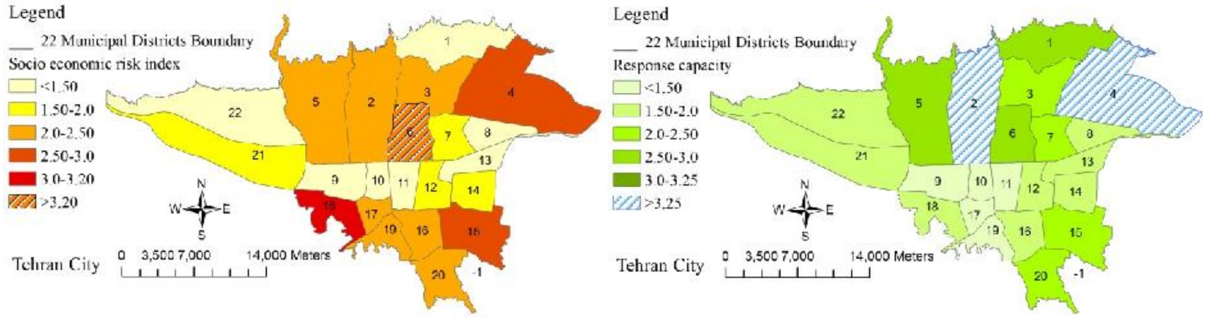
(a) **(b)**

Figure 2. (a) Normalized Physical risk index (R_{PH}), (b) Building collapsed area, at districts of Tehran



(a) **(b)**

Figure 3. (a) Normalized Human life risk index (R_{HL}), (b) Average dead person, at districts of Tehran



(a) **(b)**

Figure 4. Normalized values of (a) Socio-economic risk index (R_{SE}), (b) Response capacity (Rc), at districts of Tehran

In addition, to illustrate the benefits of the model, the results of ranking are compared with JICA (2000). In JICA study, six indicators of average seismic intensity, residential building damage ratio, death ratio, population density, open space per person, and narrow road ratio are employed and their scaled values are combined linearly for assessing the risk index. Accordingly, districts 10, 17, 12, 11 and 7 are ranked from 1 to 5, respectively.

The rank of each district for each index of this study is illustrated in Table (3). As seen, the rank of district 17 and 12, which is 2nd and 4th, respectively, are rather similar to JICA results. However, there is a big difference in rank score of some other districts such as 4 and 15. District 15 is the first and district 4 is the 3rd priority of the mitigation in our estimations, while in JICA report they are at 17th and 20th step, respectively. The comparison of the results with JICA demonstrates the importance of including all the various aspects of risk and response capacity for seismic risk assessment, which are not properly assigned in JICA study. Moreover, we believe that the indicator of average seismic intensity, which included in JICA model, should not be considered as a separate indicator since the risk is a combination of hazard and vulnerability. Also, the ratio of damage and death (for assessing the indicators of residential building damage ratio and death ratio in JICA) may not be a reasonable parameter for comparison of overall risk and estimation of mitigation priorities among different districts. The above comments can partly justify the main reasons for dissimilarities between the current study and JICA results.

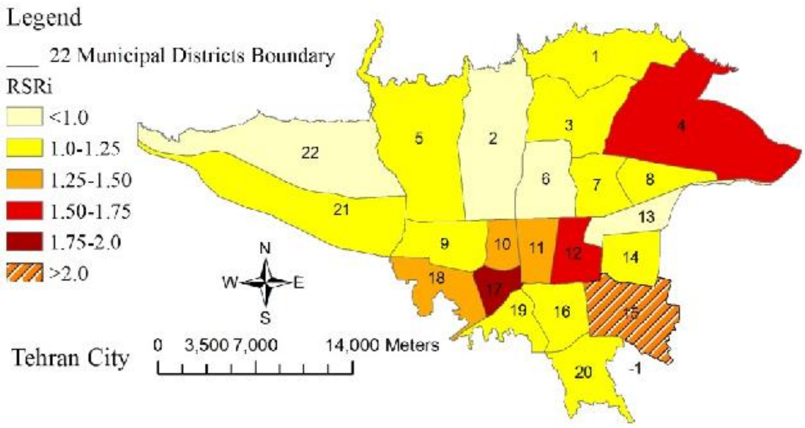


Figure 5. Normalized values of relative seismic risk index (*RSRi*), at districts of Tehran

Furthermore, from Table (3) the rank of *RSRi* by considering the actual values of *Rc* (*RSRi* with *Rc*) can be compared with the results of *RSRi* by setting the value of *Rc*=1 for all districts (*RSRi* without *Rc*). This comparison can illustrate the significant effect of considering response capacity term in estimation of the seismic risk and determination of mitigation priorities. The results show that by employing real amounts of *Rc*, the *RSRi* rank in many districts (such as 1, 2, 5, 6, 9, 10, 11, 17 and 19) is changed significantly. Accordingly, district 2 which has the 7th priority of risk mitigation among the others (as shown in Table 3) falls to 20th, and the rank of district 6 is changed from 10th to 19th. On the contrary, the *RSRi* rank of district 10 is changed from 17th to 6th due to inclusion of response capacity term.

The results of this study in addition to results of risk assessment at Tehran in case of Ray Fault Scenario Earthquake, which is presented by Hajibabaee et al. (2014), illustrate the high priority of risk reduction and mitigation activities for districts 15, 17, 12 and 18, which are among the five highest rank scores in both study results. Also, in both study, districts 2, 13 and 22 are among low priority districts. The contribution of each indicator in overall risk at each district can guide decision makers and city managers to understand the deficiencies and make appropriate decisions for mitigation and risk reduction activities.

CONCLUSION

In this paper, a new method was introduced for comprehensive assessment of seismic risk in urban areas. The method includes a set of physical, human life and socio-economic indicators to assess the overall seismic risk. Furthermore, four indicators of planning, resource, accessibility and evacuation capacity were presented to measure the response capacity. This methodology by defining new indicators and mathematical relations makes an improvement in assessing the risk in urban areas, where the required data for absolute assessment of losses and casualties are not available. The improvement of the results was verified in this paper by estimation the risk of Tehran city in case of North Tehran Fault Scenario Earthquake and comparing the results by those from JICA (2000). The main features and improvements of the model are presentation of a comprehensive set of indicators and evaluation of them based on relative scheme and new mathematical relations as well as definition of hazard factors and including the response capacity term. Moreover, native characteristics of the model such as using local fragility curves, collapse rates, casualty rates and population distribution parameters make the model suitable to be used for Iranian cities. However, it can be easily modified for implementing in other cities of the world.

Table 3. District distribution regarding to total rank of main indices

	Main indices					
Total rank	R_{PH}	R_{HL}	R_{SE}	*Rc*	*RSRi without Rc*	*RSRi with Rc*
	District number					
1st	15	4	6	2	15	15
2nd	4	15	18	4	4	17
3rd	1	1	4	5	1	4
4th	12	3	15	6	3	12
5th	20	12	17	1	12	18
6th	16	8	19	3	5	10
7th	2	5	20	7	2	11
8th	3	2	5	20	18	3
9th	5	7	16	15	16	16
10th	22	17	2	13	6	19
11th	11	16	3	16	17	8
12th	18	14	21	22	8	1
13th	21	10	7	8	7	9
14th	6	11	12	14	20	14
15th	19	18	14	21	11	5
16th	10	6	10	12	14	7
17th	14	13	9	18	10	20
18th	7	20	11	11	21	21
19th	17	21	1	10	19	6
20th	8	9	8	19	13	2
21st	13	19	13	9	9	13
22nd	9	22	22	17	22	22

Highest risk

Lowest risk

REFERENCES

Amini Hosseini K, Hosseini M, Jafari MK and Hosseinioon S (2009) Recognition of Vulnerable Urban Fabrics in Earthquake Zones: A Case Study of the Tehran Metropolitan Area, Journal of Seismology and Earthquake Engineering (JSEE)**,** 10(4): 175-187

Bahrainy H (1998) Urban Planning and Design in a Seismic-Prone Region (Rasht in Northern Iran), Journal of Urban Planning and Development, 124(4): 148-181

Birkmann F (2007) Risk and vulnerability indicators at different scales: Applicability, usefulness and policy implications, United Nations University, Institute for Environment and Human Security (UNU-EHS), Journal of Environmental Hazards, 7, 20–31

Barbat AH (2003) Vulnerability and Disaster Risk Indices from Engineering Perspective and Holistic Approach to Consider Hard and Soft Variables at Urban Level, IADB/IDEA Program of Indicators for Disaster Risk Management, http://idea.unalmzl.edu.co, Universidad Nacional de Colombia, Manizales

Cardona OD, Carreno M and Barbat AH (2007) Urban Seismic Risk Evaluation: A Holistic Approach, Natural Hazards, 40:137–172

Cardona O, Carreno M, Barbat AH and Suarez D (2009) Holistic evaluation of risk in the framework of the urban sustainability, CIMNE monograph, Technical University of Catalonia, Barcelona, Spain

Davidson R and Shah HC (1997) A multidisciplinary urban earthquake disaster risk index, Earthquake Spectra, 13(2):211–223

Frughi S (2010) The assessment of urban fabric social vulnerability in earthquake, A case study: Zanjan fabric area, Supervisor M. Ahadnejad-Reveshty, MSc thesis in geography and urban planning, Zanjan University, Iran

Ghadiriy M (2008) The relationship between cities social construction and level of vulnerability in earthquake against, A case study: Neighborhoods of Tehran Metropolis, Supervisor, A. Eftekhari, PhD thesis in geography and urban planning, Tarbiat Modares University, Tehran, Iran

Ghayamghamian MR, Mansouri B, Amini Hosseini K, Tasnimi AA and Govahi N (2011) Development of fragility and fatality functions as well as site amplification factor in Tehran, Tehran Disaster Mitigation and Management Organization

Hajibabaee M, Amini Hosseini K, and Ghayamghamian MR (2013) A new method for assessing the seismic risk of urban fabrics in Iran, Journal of Seismology and Earthquake Engineering (JSEE), Vol. 15, No 1

Hajibabaee M, Amini Hosseini K, and Ghayamghamian MR (2014) Earthquake risk assessment in urban fabrics based on physical, socio-economic and response capacity parameters (A case study: Tehran city), Nat Hazards, DOI 10.1007/s11069-014-1300-7

Hessami K, Jamali F and Tabassi H (2003) Active Fault Maps of Iran, Seismotectonic Dept., Seismology Research Center, IIEES, Iran

Japan International Cooperation Agency (JICA) (2000) The study on seismic microzoning of the Greater Tehran Area in the Islamic Republic of Iran, Final report to the Government of the Islamic Republic of Iran, Tokyo, Japan

Khazai B, Kilic O, Basmaci A, Konukcu B, Sungay B, Zeidan A, and Wenzel F (2008) Megacity Indicators System for Disaster Risk Management-Implementation in Istanbul, Megacity Istanbul Project Reports Municipality Disaster Management Center (AKOM), Istanbul, Turkey

Mansouri B, Ghafory Ashtiany M, Amini Hosseini K, Nourjou R and Mousavi M (2010) Building seismic loss model for Tehran using GIS, Earthquake Spectra, 26(1): 153-108

Motamed H, Khazai B, Ghafory Ashtiany M and Amini Hosseini K (2012) An Automated Model for Optimizing Budget Allocation in Earthquake Mitigation Scenarios, Natural Hazards, DOI: 10.1007/s11069-011-0035-y

Zebardast E (2007) Mapping Social Vulnerability to Earthquake Hazards by Using Analytic Hierarchy Process (AHP) and GIS in Tehran City, Proceedings of Mapasia 2007 conference, Kuala Lumpur, Malasia