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Assessment of Seismic Risk in Istanbul*

Seda KUNDAK
Handan TÜRKOĞLU

Istanbul Technical University
Department of Urban and Regional Planning,
Taskisla, 80191, Taksim
Istanbul TURKEY
kundak@itu.edu.tr
turkoglu@itu.edu.tr

Abstract

The 1999 earthquakes occurred in Turkey caused destructions in every field and level in nation wide with the high number of deaths and injuries, the remarkable rates of collapsed and heavily damaged buildings and the interruption of business activities in long-term. In the last 5 year-period, various scientific researches focusing on seismic issues have investigated the relationships among seismicity, site conditions and vulnerability. Moreover, with the co-operations of central and local governments, universities and international agencies, many comprehensive projects have been carried out.

Despite 1999 earthquakes had slight effects on Istanbul, the probability of a great earthquake (estimated to occur up to 30 years), has accelerated the attempts on risk evaluation, development of mitigation strategies, readjustment of disaster management system and so on. The primary studies on this field are focused on understanding seismicity and site conditions at large scale so that the earthquake maps produced show risky zones related to geological indicators. Aftermath of many great disasters, it has been observed that land-use decisions, demographic and economic pattern are the key components which increase or decrease the vulnerability level of settlements.

In this context, the aim of this paper is to evaluate vulnerability components affecting risk levels and to explore risky zones of Istanbul. In this paper, urban and seismic indicators (i.e. site conditions, demography, land use, economy) have been aggregated and factor analysis has been used in order to reveal principal components of earthquake risk in Istanbul.

Keywords: earthquake, risk analysis, vulnerability, Istanbul

* For the final version of this paper, please contact to authors

1. Introduction

In general terms, risk can be defined as the combination of probability of occurrence and the consequence of a specified hazardous event. Otherwise, the value of risk depends on the severity of hazard and the vulnerability of the elements which will be affected by the hazardous event. In the literature, there are many definitions and discussions on the risk assessment and its components (Olshansky and Wu, 2004; Meroni and Zonno, 2000; Deyle et al, 1998; Blaikie et al, 1994; Okuyama ve Chang, 2004; Coburn ve Spence, 1992, Reiter, 1990*).* "*Hazard refers to an extreme natural event that poses risks to human settlements; vulnerability is the susceptibility of human settlements to the harmful impacts of natural hazards and risk is the possibility of suffering harm from a hazard*" (Deyle et al, 1998). Blaikie et al. (1994) have defined the vulnerability components (the progression of vulnerability) and their interactions with hazards in the pressure and release model (Figure 1). In the root of vulnerability, it lays some remote influences which reflect the distribution of power in a society such as economic, political and demographic aspects. The lack of necessary adjustments and the pressure of external forces lead the root causes of vulnerability to form a fragile community against natural hazards. Finally, local soil conditions, lack of quality in building and infrastructural stocks and low risk perception of both community and public authorities cause high vulnerability level in settlements.

Seismic risk assessment requires data from different level which present both vulnerability and hazard of a region. It can be defined "*…as the probability of losses directly or indirectly provoked by earthquakes, losses that might be suffered by the population and by the built environment as well as by the economic system."* (Meroni and Zonno, 2000). However, urban areas are complex structures to explore the inter-relationships of physical, social, demographic and economic aspects. There is always the chain reaction among urban components which causes difficulties to assess them. Reiter (1990) describes seismic risk analysis as the exploration of seismic hazard and data reflecting the current feature of the site in order to reveal all the probabilities which will trace the level of impact.

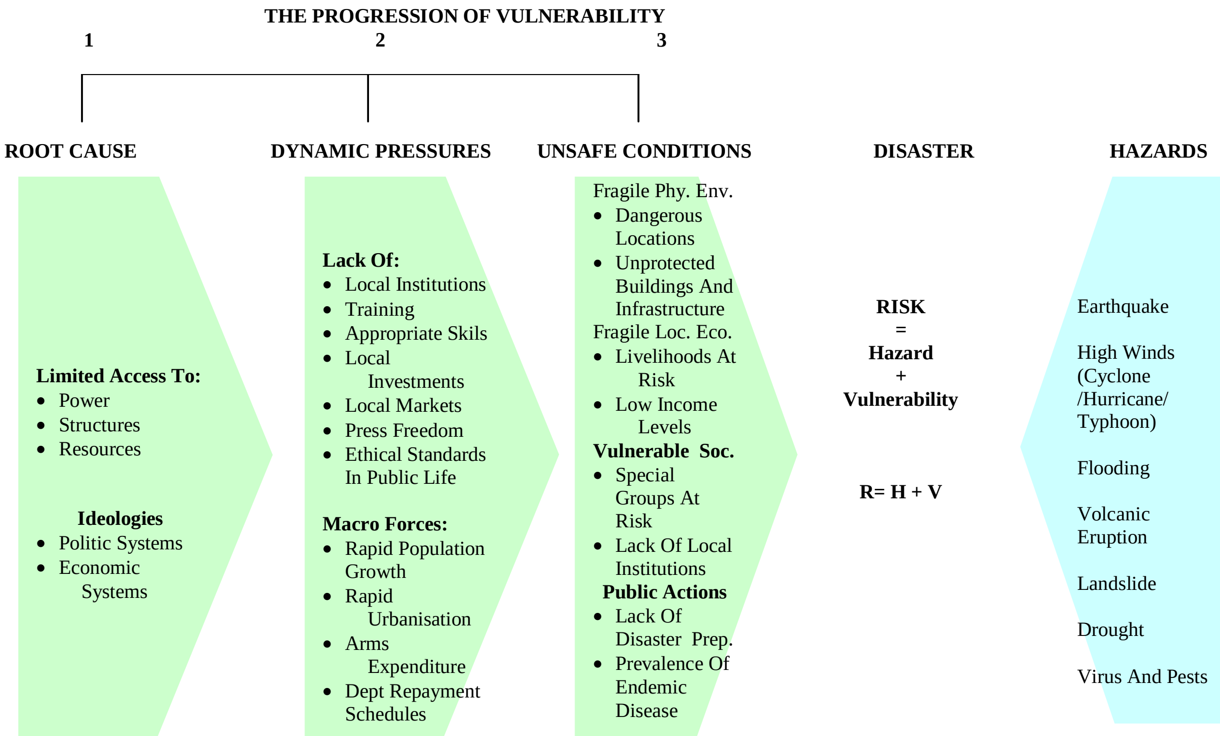


Figure 1 – Pressure and Release Model (Blaikie et al, 1994)

The aim of this paper is to represent a macroscopic perspective to risk levels in Istanbul, caused by a probable earthquake expected in Marmara Sea, on North Anatolian Fault. In the second section of the paper, earthquake vulnerability components will be discussed. Section 3 evaluates Istanbul as an earthquake-prone metropolis and gives information on past earthquakes occurred in this region. Section 4 includes database construction, principle component analysis used in this study and findings. In the last section, results of the study will be evaluated.

2. Earthquake Vulnerability in Urban Areas

Vulnerability can be described as *"… inherent characteristics of a system that create the potential for harm but are independent of the probabilistic risk of the occurrence (event risk) of any particular hazard or extreme event…"* (Sarewitz et al, 2003). Vulnerability in urban areas can be investigated according to environmental, physical, socio-demographic and economic structures of settlements.

Environmental vulnerability refers the susceptibility of natural sources against natural and technological hazards. For instance, collateral hazards triggered by earthquakes such as urban fires and damaged on hazardous industrial facilities can cause contamination of natural sources such as forests, underground water and so on.

Physical vulnerability corresponds to the both structural and infrastructural fragility of a settlement. Beside the building and infrastructure construction quality, the occupation type of the elements plays an important role in defining physical vulnerability. However, there can be some difficulties in gathering inventory data required in identification physical vulnerability. Therefore, Bendimerad (2001) proposes "tiered classification" which provides different layers of resolution in data (i.e. first tier of data for building occupancy: residential, commercial, etc; second tier of data represents the type of occupancy such as single family houses, retail trade etc.).

Socio-demographic vulnerability is connected one hand to the access to resources, political power and representation, social networks and connections, beliefs and customs (Cutter et al, 2003), and on the other hand, to the age, gender and race indicators of the population. These components affect the risk perception and the precautions taken by community for any kind of hazard.

Economic losses by severe earthquakes can cause long-term reductions in the growth of a nation's economy and trigger inflation. Therefore, evaluation of the economic losses can be considered regarding to their share in country's gross national product (GNP).

Coburn and Spence (1992) argued that "*the poorer nations with lower GNP, tend to be more vulnerable to the economic impact of a costly earthquake, even though in absolute terms, the cost of the damage may not be as high as elsewhere*". Hence, economic vulnerability forms highly complex structure to evaluate regarding to its likelihood effects. Rose (2004) suggests evaluating economic structure of a region by considering of both the stock values (equipment) and flow volumes (input-output). Moreover, in the case of a hazardous event, it should be taken into consideration the market values and the replacement values of the objects affected. The replacement value of a work place can be lower to its market value which is connected to its contribution to the regional or national accounts.

In urban areas, the vulnerability components cited above can cause chain reactions in the occurrence of natural or technological hazards. For instance, after an earthquake, some urban facilities can be still working, however, if the main transportation roads are severely damaged and if there is not possible to access to these facilities, it can be assumed that these facilities will not be efficient aftermath of a disaster. This statement is called as "systemic vulnerability". Besides evaluating the vulnerability components separately, it is also crucial to investigate their relationship in order to assess earthquake risk.

3. The North Anatolian Fault and Istanbul

1300 km-long North Anatolian Fault system, extending from east side through the west side of Turkey has been studied by numerous researchers in order to explore its characteristics (Ambraseys 1970, Barka 1992, Stein et al 1997, Papazachos et al 2002). The common output of these studies is that North Anatolian Fault (NAF) can produce major earthquakes with high frequency of occurrence. Moreover, settlements features situated in NAF zone increase the interest on this fault. Western extension of NAF passes through the Marmara Region which is the most industrialized and developed part of the country. Istanbul, the primate city of Turkey, is situated in this region as well.

Istanbul, due to its strategic location and historical background as the capital of three empires, has been the heart of national and international economic activities in Turkey. In the beginning of 1950's, the development of Turkish economy reinforced the dominant economic role of Istanbul in all over the country. In this period, the rapid population growth due to migration from rural part of the country caused rising density and expending urban area. However, the planning processes remained insufficient against this "rapid development" and Istanbul gained a complex and uncontrolled urban pattern. Today, within its 12 million inhabitants, Istanbul is the most populated city in Turkey.

Expansion of urban land in Istanbul showed linear development in the southern part of the city, from the eastern side to western side, parallel to NAF. Newly developed sub-centers and industrial areas enabled to change mono-centric structure of Istanbul to policentric structure. Despite, this development process tends to arrange inner-city flows and protects forest land in the northern part of the city, earthquake vulnerability increased in Istanbul.

After the Kocaeli and Duzce earthquakes (1999), which occurred in the most industrialized region in Turkey, total economic losses reached about $22 billion which represents 12% of GDP in 1999 (SED). The probability of seismic hazard for Istanbul has not been over within these earthquakes. Several researches indicate that according to the historical seismicity of the region, a major earthquake is expected in Marmara Sea which will severely affect Istanbul.

4. Earthquake Risk Assessment for Istanbul

This study aims to represent a macroscopic perspective to risk assessment in Istanbul, for a probable earthquake expected in Marmara Sea, on North Anatolian Fault (NAF). According to the historical records of NAF activities, Istanbul experienced two major earthquakes in 1509 and in 1766 which destroyed the whole city. Today, many researchers argue that the return period of "major earthquake" is over.

To examine the earthquake risk in Istanbul, 15 variables are used which represent hazard and urban exposure for 613 neighborhood of Istanbul Metropolitan Area. The methodology of the empirical part of this study is based on principle component analysis which provides to evaluate risk variables through the main factors.

4.1. Data Construction

Originally, 27 variables were collected, but after testing for multi-collinearity among the variables, 15 independent variables were used in the statistical analyses (Table 1). The variables are described as follows:

Average age of the neighborhood: The age indicator of the settlements plays an important role in evaluating structural and infrastructural resilience (Davidson, 1997; Kakhandiki, 1998). In the old settlements, beside the age of buildings, the aging infrastructural facilities are vulnerable to not only any kind of hazards but also to daily usage that they are faced to create some malfunctioning. In the case study, the average age of the neighborhoods has been calculated according to the average age of the buildings.

Number of Housing Units in the neighborhood: Land use pattern of settlements reflects the usage type of the units during the time. When the majority of the units are indicated as residential, the usage of the units is concentrated in the evening and night time. This distinction helps to evaluate the population exposure in the case of any kind of hazard.

Percentage of un-planned areas: The term of “un-planned area” refers the settlements which have lower building quality with the lack of necessary infrastructure. After 1950’s, because of the rapid immigration, the un-planned settlements covered the fringes of the city and extended through both eastern and western side.

Table 1 – List of Variables and Sources

Abbreviation	Name	Source
AGE	Average age of the neighborhood	Own elaboration using “Building Census of the Year 2000” (State Institute of Statistics)
HOUSE	Number of Housing Units in the neighborhood	“Building Census of the Year 2000” (State Institute of Statistics)
UN-PLANNED	Percentage of un-planned areas	Own elaboration using “Master Plan 1994” (Istanbul Greater Municipality)
POP-AGE	Percentage of the population aged 0-12 and 65+ in the neighborhood	Own elaboration using “Population Census of the Year 2000” (State Institute of Statistics)
LANDVALUE	Average land value in the neighborhood	Own elaboration using “National Real Estate 2002”
STUDENTS	Number of students attending the neighborhood schools	Own elaboration using “Ministry of Education 2004”
POP-DENSITY	Population density in the neighborhood	“Population Census of the Year 2000” (State Institute of Statistics)
BUILD-DENSITY	Building density in the neighborhood	“Building Census of the Year 2000” (State Institute of Statistics)
NON BUILT-UP	Percentage of non built-up area in the neighborhood	“Istanbul Greater Municipality and JICA Project 2002”
HAZARDOUS-LANDUSE	Number of hazardous land use units in the neighborhood	Own elaboration using “Building Census of the Year 2000” (State Institute of Statistics)
WORK PLACE	Number of work places in the neighborhood	“Building Census of the Year 2000” (State Institute of Statistics)
ARS-7.7	Neighborhood average of the acceleration response spectrum for an earthquake with the magnitude of 7.7	Own elaboration using “Istanbul Greater Municipality and JICA Project 2002”
SLOPE	Percentage of the areas with a slope more than %30 in the neighborhood	Own elaboration using “Istanbul Greater Municipality and JICA Project 2002”
HEALTH	Number of health facilities in the neighborhood	Own elaboration using “Ministry of Health 2004”
PATIENT BED	Number of patient bed in the neighborhood	Own elaboration using “Ministry of Health 2004”

<u>Percentage of the population aged 0-12 and 65+ in the neighborhood</u>: The age indicator plays an important role in the case of emergency caused by any kind of hazard (Davidson 1997, Kakhandiki, 1998, Cutter 2003). Beside the structural resilience of the settlement, the capability of the population in saving themselves during the crises is the one of the key components of vulnerability. In this group two main critical age groups are indicated as vulnerable: young people between the age of 0-12 and elderly people within the age more than 65.

Average land value in the neighborhood: Land value can be used to describe different features of a settlement. In previous researches, the relationship between land values and urban pattern had been studied as an indicator of urban decentralization and variation of the land prices according to the land use types (Heikkila et al, 1989; McDonalds and McMillen, 1990; Peiser, 1987; Dowall and Treffeiser, 1990, Guntemann, 1996, Ciraci and Kundak, 2000). In the perspective of vulnerability to hazards, land value reflects the economic exposure of the settlement.

Number of students attending the neighborhood schools: Schools are the critical facilities in evaluating vulnerability. During the day time, school buildings are occupied by children of various ages, and in the case of hazardous event, it is important to identify the location of the young people in order to plan evacuation strategies. In this study, the number of students attending the neighborhood schools has been calculated to explore the population exposure during the day time.

Population density in the neighborhood: Population density is the main population exposure which indicates demographic vulnerability of a settlement. The high density level in population can make difficult the search and rescue works after natural or technological hazards.

Building density in the neighborhood: Building density describes physical exposure of a settlement. Dense settlements are usually suffered by scarcity of open spaces which are vital on emergency moments such as earthquakes.

Percentage of non built-up area in the neighborhood: Non built-up areas are always potential for settlements in order to provide new recreational or urban facilities in the point of urban planning view. Likewise, regarding to the natural hazards, these areas are potential to evacuate people during the crises and provide temporary shelters for affected people.

Number of hazardous land use units in the neighborhood: Hazardous land uses such as chemical factories can cause secondary hazards in the occurrence of natural hazards. Especially gas stations near to the residential and commercial areas cause potential hazards such as explosion and urban fire.

Number of work places in the neighborhood: Business activities and their capacities help to improve the economic asset of the settlements. However in the case of natural hazard, work places are fragile regarding to both their stock value and their contribution to regional or national budget. In this study, number of work places is used in order to explore the economic exposure of the neighborhoods.

Neighborhood average of the acceleration response spectrum for an earthquake with the magnitude of 7.7: The effects of earthquakes vary according to the magnitude, distance from the source and site effect. In this study, the acceleration response spectrum for an earthquake with the magnitude of 7.7 has been used as the hazard indicator.

Percentage of the areas with a slope more than %30 in the neighborhood: The earthquakes are able to trigger secondary hazards such as land slides. The areas with a slope more than 30% have been indicated in order to point out the areas which have the potential of producing land slides.

Number of health facilities in the neighborhood: After the big hazards, the most critical urban facility is health services. Their location and their capacities play a crucial role in order to provide first aid and further health services for severely injured people.

Number of patient bed in the neighborhood: Beside the health facilities, hospitals and their patient bed capacities are important to provide necessary medical and surgery assistance.

4.2. Principle Component Analysis

Principle Component Analysis is generally used for reducing the number of variables in a data set and for obtaining useful two-dimensional views of a multi-dimensional data set. A total of 5 factors were produced, which explained 66.4 percent of the variance in the neighborhoods (Table 2).

Factor 1 – Exposure

The first factor identified the exposure of neighborhoods as measured by neighborhood age, number of housing units, percentage of un-planned areas, vulnerable age groups, average land value and number of students attending the neighborhood's schools. The exposure factor explains 18.7% of the variance. The average age and the land value of the neighborhood both load negatively on this dimension. This aspect reveals on one hand that the older parts of the city were developed according to the planning regulations while the newest parts are dramatically grown on the un-controlled circumstances and on the other hand, the increase on the land values reflects economic wealth of the community which is able to reinforce their built-up environment (Table 3, Table 4).

Factor 2 – Density

The second factor identified the density of neighborhoods as measured by population density, building density and percentage of non built-up areas and it explains 14.3% of the variance. Obviously, percentage of non built-up area load negatively on this dimension. This means, open spaces and green areas are vital urban elements which can be provided in order to decrease vulnerability of the settlement (Table 3, Table 4).

Table 2 – Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squares Loadings		
Component	Total	% of variance	Cumulative %	Total	%of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.225	21.498	21.498	3.225	21.498	21.498	2.803	18.687	18.687
2	2.259	15.058	36.556	2.259	15.058	36.556	2.152	14.346	33.033
3	1.967	13.117	49.673	1.967	13.117	49.673	1.904	12.931	45.964
4	1.378	9.189	58.862	1.378	9.189	58.862	1.619	10.794	56.758
5	1.125	7.502	66.364	1.125	7.502	66.364	1.441	9.606	66.364
6	0.951	6.340	72.703						
7	0.738	4.921	77.625						
8	0.671	4.474	82.098						
9	0.590	3.936	86.497						
10	0.519	3.492	89.497						
11	0.484	3.224	92.721						
12	0.409	2.730	95.450						
13	0.288	1.922	97.373						
14	0.259	1.726	99.099						
15	0.135	0.901	100.00						

Table 3 –Component Matrix

	Components				
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
	Exposure	Density	Business	Hazard	Potential
Average age of the neighborhood	-,655	,363	2,411E-02	-,133	-1,862E-02
Number of housing units in the neighborhood	,667	-3,776E-02	,384	,313	,167
Percentage of un-planned area in the neighborhood	,747	,122	-4,559E-03	-,308	-7,895E-02
Percentage of the population aged 0-12 and 65+ in the neighborhood	,555	,191	1,574E-02	-,109	2,678E-02
Average land value in the neighborhood	-,693	-3,108E-02	7,821E-02	,151	,117
Number of students attending the neighborhood schools	,622	-,102	,297	,286	,226
Population density in the neighborhood	,212	,783	-,152	,263	-4,620E-02
Building density in the neighborhood	-,235	,877	-1,011E-02	-4,084E-02	-,126
Percentage of non built-up area in the neighborhood	-9,172E-02	-,705	-5,958E-02	-7,903E-02	-2,633E-02
Number of hazardous land use units in the neighborhood	,198	-,106	,841	2,601E-03	1,440E-02
Number of work places in the neighborhood	-3,554E-03	6,855E-02	,925	5,660E-02	2,986E-02
Neighborhood average of the acceleration response spectrum for an earthquake with the magnitude of 7.7	-8,647E-02	3,553E-02	-4,684E-02	,817	1,592E-02
Percentage of the areas with a slope more than %30 in the neighborhood	5,682E-02	-,219	-,132	-,733	-2,956E-02
Number of health facilities in the neighborhood	,174	-,100	,266	8,915E-02	,772
Number of patient bed in the neighborhood	-8,548E-02	-2,806E-02	-,134	-1,188E-02	,851

Factor 3 – Business Activities

The third factor represents the economic asset of neighborhoods and it explains 12.9% of the variance. Beside the value added contributing to the regional and national accounts by enterprises, the number of work places is also significant to indicate the economic activity of the settlement (Table 3, Table 4).

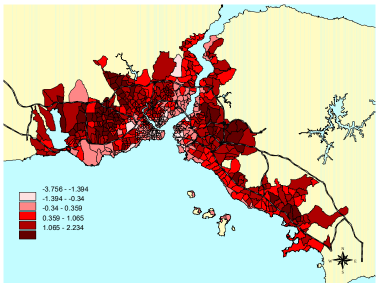
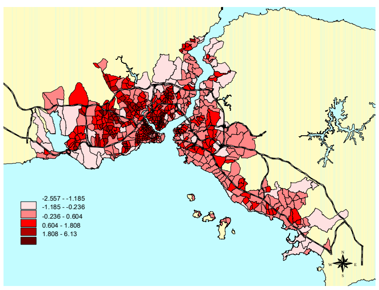
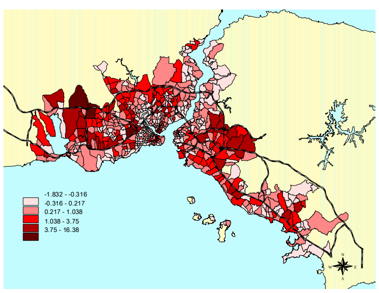
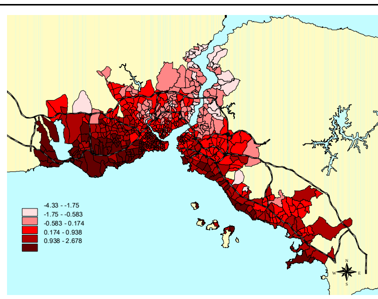
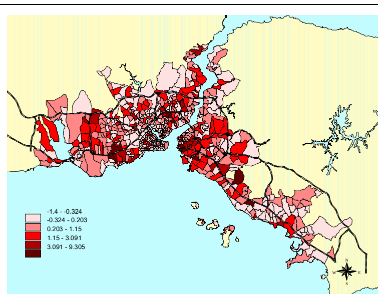
Factor 4 – Hazard

The fourth factor covers the variables related to earthquake hazard measured by acceleration response spectrum for an earthquake with the magnitude 7.7 and percentage of inclined areas for more than 30%. The hazard factor explains 10.8% of the variance (Table 3, Table 4).

Factor 5 – Potential

The last factor represents potential which can be used during crises. The potential factor explains 9.6% of the variance. In this factor, the number of health services and the number of patient beds in hospitals have been calculated in order to reveal the emergency response aftermath of a severe earthquake (Table 3, Table 4).

Table 4 – Components and Maps of Factors

Factor Maps	Components of Factors
	Factor 1 – Exposure • Age of the Neighborhood • Number of Housing Units • Percentage of un-planned areas • Percentage of vulnerable population • Land value • Number of students
	Factor 2 – Density • Population Density • Building Density • Percentage of non built-up areas
	Factor 3 – Business Activities • Number of work places • Number of Hazardous land uses
	Factor 4 – Hazard • Acceleration response spectrum (M7.7) • Percentage of areas with a slope more than 30%
	Factor 5 – Potential • Number of Health facilities • Number of patient bed

4.3. Evaluation

The 5 factors produced using principle component analysis, explain 66.4% of the variation. The map which is formed by the total factor scores of neighborhoods show risky zones of Istanbul (Figure 2). In the north-eastern and the north-western part of the city, the earthquake risk is higher comparing to the other parts of the city. When the values of the variables or the main 5 factors are examined in these neighborhoods (Table 4, Figure 2), highest density in population and building, numerous educational facilities, work places, larges factories can be observed. In the southern part of these neighborhoods, risk is getting higher because of the hazard factor which refers earthquake hazard components with the average acceleration response spectrum and slope stability.

The risk levels in new and old settlements comparably differentiate each other. In the literature it is argue that old settlements are much more vulnerable than the new ones. However, in Istanbul, according to the development process which shows an un-controlled expansion after 1950's, the old settlements are much more resilient comparing to the newly developed areas in the city. This can be summarized such as; the old settlements have equilibrium in urban pattern with built-up areas and green spaces; urban facilities access all the community; transportation facilities are enriched by different modes; people living in these parts can afford average land value which is high, hence, they can also afford the cost of precautions against hazards.

The earthquake risk in the northern part of the city is the lowest due to the distance from the fault, soil conditions and urban pattern. In the western fringe of the city, the risk is high regarding to hazard and vulnerability components. Despite the eastern fringe of the city has the similar hazard condition to the western part, the urban pattern and the development process of the region help to decrease the vulnerability.

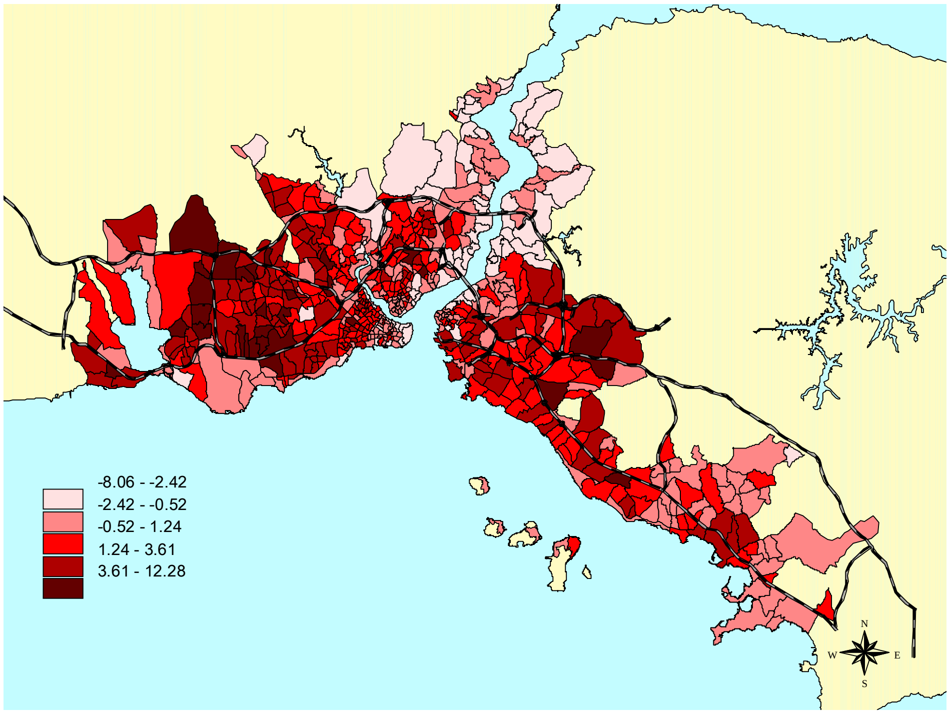


Figure 2 – Total Factor Scores

5. Conclusion

Natural hazards, especially earthquakes, can be devastating to urban areas according to their intensity and the vulnerability level of settlements. In general terms, the value of earthquake risk depends on the severity of hazard and the vulnerability of the elements which will be affected. In the case of Istanbul, with the high probability of a severe earthquake, the risk levels have been measured and examined using 15 variables which refer hazard and exposure. The first and the second factors explaining the biggest part of variance state urban pattern by development process, densities, and so on. The findings illustrate the evidence of how the vulnerability indicators are relevant in the earthquake risk assessment.

The results of Istanbul case point out the emergence of a comprehensive planning process by means of spatial re-organization and administrative adjustment. Planning and implementation processes in Istanbul require long time and big budget. Moreover, achievement of these attempts requires a well organized control and feedback system as well.

For the further researches, the systemic vulnerability can be examined in order to reveal the dependency of urban elements to each other in the case of a major disaster. This method will help to evaluate the efficiency of and the access to critical facilities such as hospitals. As the risk is quite high in some parts of the city, the risk perception of citizens, public and private sector can be investigate in order to determine the willingness to pay limits or levels.

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