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Economic loss estimation for earthquake hazard in Istanbul

Seda KUNDAK*

Istanbul Technical University

Department of Urban and Regional Planning,

Taskisla, 80191, Taksim

Istanbul TURKEY

sedakundak@superonline.com

kundak@itu.edu.tr

Abstract

Natural hazards, especially earthquakes, cause disasters when they hit large settlements such as metropolitan areas. After the first shock, the damage is counted by deaths and injuries. In a while, the destroying effects of disaster appear on economic asset of the region. Direct losses including damages in buildings and lifelines can caused non-structural or indirect losses as interruption of business activities and services. Loss estimation techniques have been developed to evaluate losses from earthquakes and other natural hazards. Recently, loss estimation models have improved due to advances in information technology and have been automated using Geographic Information Systems.

The aim of this paper is to find out economic effects of probable earthquake in Istanbul. In this study, damage ratios of the most probable and the worst-case earthquake scenarios have been used in order to estimate total damage cost from destruction of houses and interruption of business activities. Despite the loss estimation model does not include monetary losses in lifeline system, centers of administration, emergency services and historical assets, the findings show that future losses, caused by a severe earthquake in Marmara Sea, will exceed the total damage cost of Kocaeli earthquake in 1999.

* *PhD student. Advisor: Prof.Dr. Handan TÜRKOĞLU.*

Introduction

Natural disasters, especially earthquakes, can be devastating to human activities, to social organisations at every level and to economic life. After the first shock, the damage is counted by deaths and injuries. In a while, the destroying effects of disaster appear on economic asset of the region. The most obvious consequence of an earthquake is the physical destruction of the built environment. Beside the damages in houses, work places, schools, hospitals, centers of administration and historical buildings, the physical destruction may also extend beyond buildings to infrastructure (lifelines). Transportation systems, power, gas, water and communication lines may be destroyed. As a consequence of this physical damage, economy of the region is desrupted as well.

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*". As seen in Table 1, earthquakes in Nicaragua (1972) and El Salvador (1986) caused \$2.0 and \$1.5 billions damage respectively. These costs are quite low comparing with those in Italy (1980) and USSR (1988). However, while \$45 billions loss is representing 6.8% of the GNP in Italy, in Nicaragua, \$2.0 billions loss is equivalent to 40% of the GNP (Table 1).

In order to estimate probable future losses in earthquake-prone regions, loss estimation techniques have been developed. Loss estimation techniques have been studied with every aspects and consequences by engineers, economist, architects, urban planners, sociologists and so on. The sum of all these studies shows that losses caused by disasters are multifaced.

Table 1. Economic losses by major earthquakes (Coburn and Spence, 1992)

Country	Year	Billions $ damage	Loss (%GNP)
Nicaragua	1972	2.0	40.0
Guatemala	1976	1.1	18.0
China	1976	6.0	1.5
Romania	1977	0.8	3.0
Yugoslavia	1979	2.2	10.0
Italy	1980	45.0	6.8
Mexico	1985	5.0	3.0
Greece	1986	0.8	2.0
El Salvador	1986	1.5	31.0
USSR	1988	17.0	3.0
USA	1989	8.0	0.2
Iran	1990	7.2	7.2
Philippines	1990	1.5	2.7

The aim of this paper is to represent a macroscopic perspective to economic losses in Istanbul, caused by a probable earthquake expected in Marmara Sea, on North Anatolian Fault. In the second section of the paper, loss estimation techniques will be introduced. Section 3 evaluates Istanbul as a earthquake-prone metropolis and gives information on past earthquakes occured in this region. Section 4 includes database construction, loss estimation model used in this study and findings. In the last section, results of the study will be evaluated.

2. Loss estimation models

Numerous loss estimation techniques and their empirical application have been examined in various research fields. Different types of loss estimation studies are used depending on the nature of the problem and the purpose of the study. As the main aim of these techniques is to calculate probable losses regarding to any event, loss estimation models used in earthquake hazard have been developed as well to estimate impacts of any earthquake at any intensity in any place.

Bendimerad (2001) has defined loss estimation models as a powerful tool for risk assessment which provide urban planners and emergency managers with key information on potential damages and losses. His study emphasizes the difficulty in gathering inventory data required in loss estimation techniques, and 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.). Sharma (2001), argued that loss estimation is of great importance following a disaster. He emphasized the importance of developing a comprehensive database of economic, social, and demographic information to estimate the extent of losses caused by earthquake. This information will be invaluable for several purposes, including planning of relief and rehabilitation measures after a disaster and will also assist the government in monitoring the effectiveness of rehabilitation measures over time. Champell et al (2002) developed a seismic hazard model for Taiwan that integrates all available seismic hazard informations in the region to provide risk managers and engineers with a model they can use to estimate earthquake losses and manage seismic risk.

Kunreuther (2000) has investigated, risk management strategies for reducing losses from natural disasters and providing financial resources to victims of these devastating events in both developing countries and emerging economies. Chen et al. (1997), have proposed a quick and approximate estimation of earthquake loss using with detailed local GDP and population data. Their study argues that gross domestic product (GDP) of a country or a region is considered the better exposure indicator than gross national product (GNP) which includes GDP plus the net factor income from abroad and property income. The same research group have applied their model in various case studies (Chan at al 1998, Chen at al 2002). Moat et al. (2000) presented a comparative study on the performance of industrial facilities in three earthquakes (Kocaeli, Athens and Chichi) occured during 1999 and they extracted key lessons which will be able to reduce the risk. Spence et al (2003) practised loss estimation models to explore discrepancies between the model predictions and field observations from the 1999 Kocaeli earthquake. Rose and Lim (2002), investigated business interruption losses from electricity lifeline disruptions following the Northridge Earthquake. They compared the model results with a questionnaire survey as an attempt at model validation. Kunnumkal (2002) evaluated the direct and indirect economic losses from a large earthquake at national scale with special consideration for the effects of damage to the road transportation network.

In many studies, loss estimation techniques have been practiced using built environment. However, Olshansky and Wu (2001), beside the calculations of losses in current land uses, investigated the extend to which planned future land-use growth would affect the earthquake risk. They found that planned growth of 14.2% would result in a 15.8% increase over the risk to current land uses. The results of this study are important for both local governments and planners "*to be sure that they are not disproportionately planning future growth for hazardous locations*". It is obvious that earthquakes have impacts not only on the local production but also on foreign tourism and other international exchanges. Mazzocchi and Montini (2001) showed the effects of the earthquake, occured in Central Italy in 1997, on tourism business and they found out that the monetary loss related to the average tourist's expenditure exceeded $71 million between the period October 1997-June 1998. Loss estimation models are developed for other natural hazards as well. For instance, Dutta et al. (2003) developed an integrated model for flood loss estimation in a river basin. In their paper, an integrated mathematical model for simulation of flood inundation and loss estimation and its preliminary application in a river basin in Japan have been discussed.

Studies on economic impacts of earthquakes have been usually examined in two categories: a) loss caused by destruction of built environment (direct loss), and b) loss caused by interruption of economic activities (indirect loss). The loss estimation of built environment can be made by calculating the cost of reinstatement of all that was destroyed or rendered unusable by the earthquake. Likewise, the loss of production to the region's economy can eventually be estimated, however, this estimation can not be so precise because of the complexity of fiscal asset of the settlements.

In traditional engineering loss estimation models, expected loss at a site is determined by the following equation (Chen et al, 1997):

$$Loss = \sum_{B_k} \left[\left\{ \sum_{I_i} P(I_i|B_k) * \left(\sum_{dr_j} P(dr_j|I_i, B_k) * (dr_j|B_k) \right) \right\} * V_{B_k} \right]$$

where Bk is the building type k; Ii is the intensity level i; drj is the expected damage ratio j; VBk is the value of all buildings of type Bk. This equation reveals the total building damages according to a certain seismic event. Building occupency factor, lifelines and economic exposure of the region are not included in the model.

Once building damage ratio of an earthquake in a region is specified, the cost of reinstatement of buildings destroyed by the earthquake can be calculated. In year T and at site K, the absolute value of expected economic loss of the type S buildings is defined as (Chen et al, 1996):

$$E_{KS} = \sum_{D_j} \sum_{I} P_{KS}(D_j|I) * P_K(I) * b_S(D_j) * B_S$$

where PKS(I): probability of intensity ocuring in year T at site K; $P_{KS}(D_j|I)$: probability of occurence of degree Dj damage of type S buildings at site K in case of intensity I ; $b_S(D_j)$: mid value of damage ratio in case that type S buildings experience degree Dj damage; BS: total value of reconstruction for type S buildings. The total of expected economic loss of all types of buildings at site K is EKS.

As mentioned above, beside the effects on built-up area, earthquakes have impacts on region's economy because of the interruption of bussiness activities, immediately after the event. This loss is defined as indirect economic loss which extends through a long-time period. To calculate indirect losses, the most common method is using monetary indicators related to production potential of the region. This indicator might be gross national product (GNP), gross domestic product (GDP) or net value added of the bussiness entreprises. In general, GDP indicator is selected to reveal the exposure of earthquake-prone areas. For a given site with a GDP, cost of physical loss is defined as (Chen et al, 1997);

$$Physical\ Loss = \sum_{I_j} P(I_j) MDF(I_j) * GDP * g(GDP)$$

where P(Ij) is the probability of Ij in the forthcoming years, MDF(Ij) is the Mean Damage Factor to represent the hazard-exposure-loss relation given intensity Ij. g(GDP) is a function to correlate the total social wealth with macroscopic indicator GDP.

Loss estimation models are flexible that one may transform basic equations depending on the nature of the problem and the purpose of the study. For instance, in the equation (2), when the building type parameter is replaced by building occupency grouped into building types; losses in residential, commercial or industrial buildings may be calculated. This feature of the model enables researchers for estimating earthquake losses from macroscopic to microscopic scale.

3. Earthquake-prone metropolis: 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 point of these studies is that North Anatolian Fault (NAF) can produce major earthquakes with high frequency of occurence. For instance, while the San Andreas fault in California, as a close analogue of NAF, produced just two severe earthquakes (M>6.7) in 20^{th} century, NAF suffered ten such shocks. Moreover, settlements features situated in NAF zone increase the interest on this fault. Western extention 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. Moreover, Istanbul undertakes several leading roles in cultural, financial, commercial, tourism and service functions. This feature of the city certainly reflects on nation’s economy. Istanbul’s contribution to tax revenues reaches 42% (IBB), its contribution to the budget is 34% (IBB) and its share in GDP exceeds 20% (SIS).

Expansion of urban land in Istanbul showed linear development in the southern part of the city, from the eastern side to western side, paralel to NAF. Both population and building density increased in the fringes of the city. Newly developed sub-centers and industrial areas enabled to change monocentric 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. When 1999 Kocaeli earthquake hit the Marmara Region, in Istanbul, Avcilar (in south-west) and Tuzla (in south-east) were the most affected districts with collapsed buildings.

After the Kocaeli and Duzce earthquakes (1999), which occured 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. Researches carried by local government, institutions and universities accelerated in this period. A comprehensive project named “A Disaster Prevention/Mitigation Basic Plan for Istanbul” was carried by Istanbul Greater Municipality in cooperation with Japan International Cooperation Agency (JICA)*. In

** This project will be refered as “IBB & JICA Project” in the rest of the paper* this research, probable earthquake intensities and their impacts on built environment were examined. The study started right after the earthquake and final report has been released in the end of 2002.

4. Economic Loss Estimation Model for Istanbul

This study aims to represent a macroscopic perspective to economic losses in Istanbul, caused by 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 were called as "doomsday". These earthquakes destroyed the whole city. Today, many researchers argue that the return period of "major earthquake" is over.

In this paper, some economic losses caused by probable "major earthquake" have been discussed by focusing on destruction of houses and interruption of business activities. Two earthquake models developed in IBB & JICA Project and their three-leveled damage ratios (highly-moderate-partly damaged) have been used in order to express losses in built environment. Therefore, in this study, economic losses have been calculated in three different damage levels of two different earthquake magnitudes for both in case of housing and business units.

4.1. Database Construction

In this study, 615 neighborhoods of Istanbul have been examined in the perspective of houses and business stock vulnerability. The building damage ratios of two earthquake scenarios with magnitude of 7.5 (most probable-case scenario-M7.5) and 7.7 (worst-case scenario-M7.7) for each neighborhood have been included in the database. As an indicator of economic exposure of neighborhoods, GDP is used in this study.

Damage ratios of M7.5 and M7.7, which present seismic hazard indicators, had been calculated for each neighborhood unit in IBB & JICA Project. This parameter is the function of geology, geomorphology, seismicity, soil and earthquake energy attenuation characteristics. Damage classification is represented into three category: a) partly damaged, b) moderate damaged; and c) heavily damaged. Partly damaged buildings are still usuable buildings but they require reinforcement because their stability against earthquake might be reduced. Moderate damaged buildings are standing buildings but they are not safe for living inside before restoration. Heavily damaged buildings are totally or nearly collapsed buildings that require reinstatement. According to the past earthquake experiences in Turkey, the approximate cost had been calculated. Housing that has collapsed or is too heavily damaged to be inhabitable will need to be demolished and rebuilt at an estimated cost of US$20.000/unit. Furthermore, contents cost of housing unit which referes all the equipment of a house is also added. According to ensurence compensations of an average house, it is about US$20.000/unit. Housing with moderate damage is estimated to cost US$ 8.000/unit for repairs and light damage reparable at US$3.000/unit (World Bank Report, 1999).

The data set representing losses caused by business interuption includes number of bussiness units and the share in GDP (2001) of each neighborhood. This data enable to calculate indirect losses caused by earthquake. After major earthquakes, some work places can not continue their production for a while because of loss in their employees or buildings. Moreover, in many case, major earthquakes cause deep and long-term monetary losses in the fiscal asset of both region and country in the mean of tax contribution, value added and share in GDP and GNP. As mentioned in the first part of this paper, these losses can cause long-term reductions in the growth of a nation's economy and trigger inflation.

4.2. Model Construction

As discussed in the second part of the paper, loss estimation models are flexible that one may transform basic equations depending on the nature of the problem and the purpose of the study. In the Istanbul case, to view big picture, database and model are designed in macroscopic scale. Estimated economic loss in each neighborhood ($Loss_N$) is represented by the sum of total damage cost of housing units ($Loss_{H_N}$) and total damage cost from interruption of business activity ($Loss_{B_N}$).

$$Loss_N = Loss_{H_N} + Loss_{B_N}$$

Damage cost of housing units can be expressed as:

$$Loss_{H_N} = DCH_{h_N} + DCH_{m_N} + DCH_{p_N} + CCH_{h_N}$$

where;

DCH_{h_N} = Damage cost of heavily damaged houses

DCH_{m_N} = Damage cost of moderate damaged houses

DCH_{p_N} = Damage cost of partly damaged houses

CCH_{h_N} = Contents cost of heavily damaged houses

Damage cost from interruption of business activity can be expressed as:

$$Loss_{B_N} = D_{B_N} \ x \ GDP_N$$

where;

D_{B_N} = Number of heavily damaged work places

GDP_N = GDP of neighborhood

4.3. Findings

If the most probable-case scenario (M7.5) occurs on NAF, the expected economic loss in Istanbul can be $26.04 billion (Figure 1). In this case total damage cost of housing units can reach $17.46 billion (Figure 2). In the southern part of the European Side of Istanbul, building and population density are higher than the other parts of the city. However, the geological structure of the area does not support this dense urban pattern.

During the Kocaeli earthquake, despite the long distance from the epicenter, this area was severely affected. Another area affected during the previous earthquake was the southern part of the Asian side of the city. According to the model tested in this study, the total lost caused by housing units is not as higher as in the area mentioned above, because of the low number of housing units. Total damage cost from interuption of business activities can be $8.57 billion (Figure 3). Monetary losses increase in the bussiness districts of the city. Especially, a newly developed subcenter in the southern part of the European Side, is under high risk.

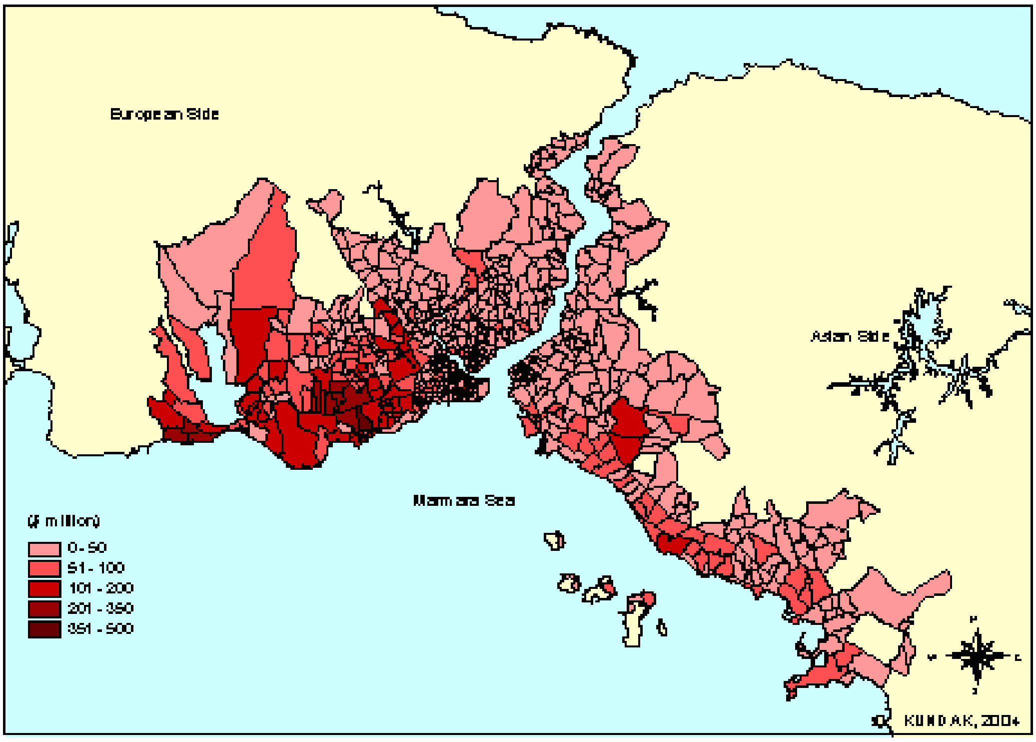

Figure 1. Total Damage Cost (M=7.5)

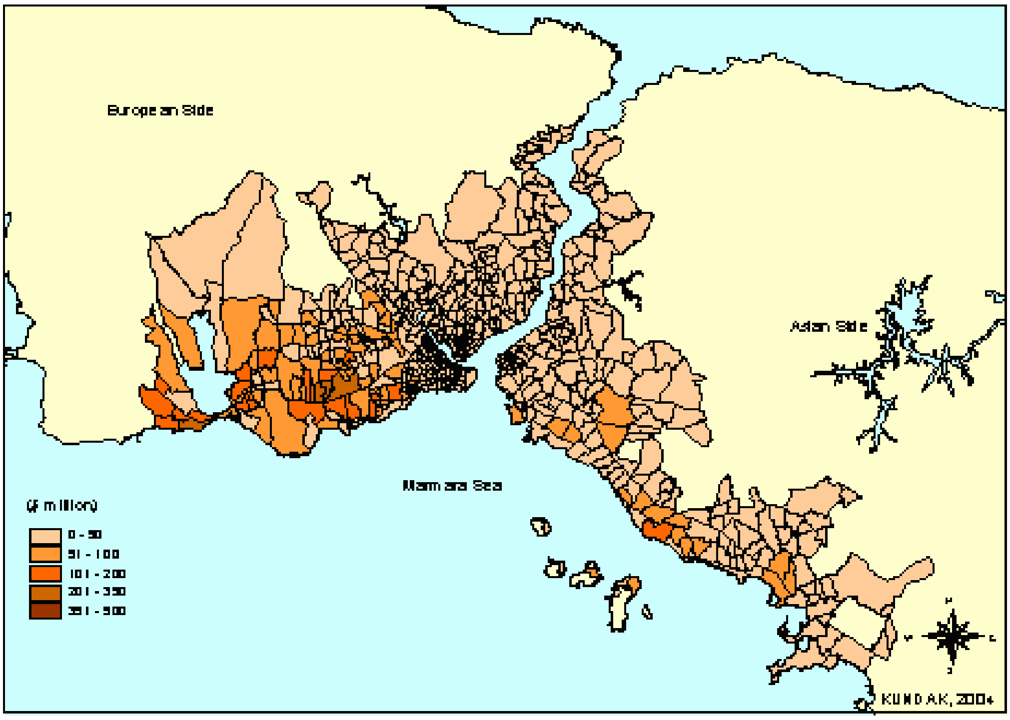

Figure 2. Total Damage Cost of Housing Units (M=7.5)

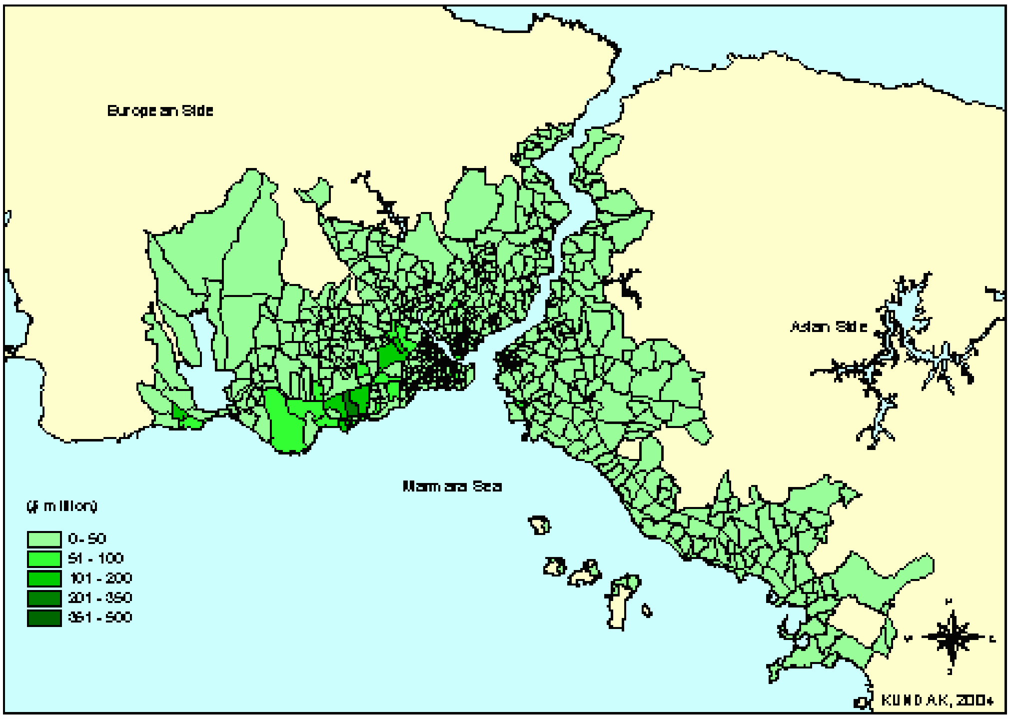

Figure 3. Total Damage Cost From Interruption of Business Activity (M=7.5)

If the worst-case scenario (M7.7) occurs on NAF, the expected economic loss in İstanbul can be $29.87 billion (Figure 4). In this case total damage cost of housing units can reach $20.07 billion (Figure 5). As some residential areas in the city fringes showed unplanned development, their building qualities are lower than those in inner city. Despite some neighborhoods are far from NAF, they can be severely affected from earthquake and their monetary loss in houses can be exceed $100 million. Total damage cost from interuption of business activities can be $9.79 billion (Figure 6). In this case, beside newly developed sub-centers, industrial areas can be damaged as well. Their damages can be resulted in environmental pollution, urban fires and the other colleteral hazards. Therefore, the total cost increases twice or more.

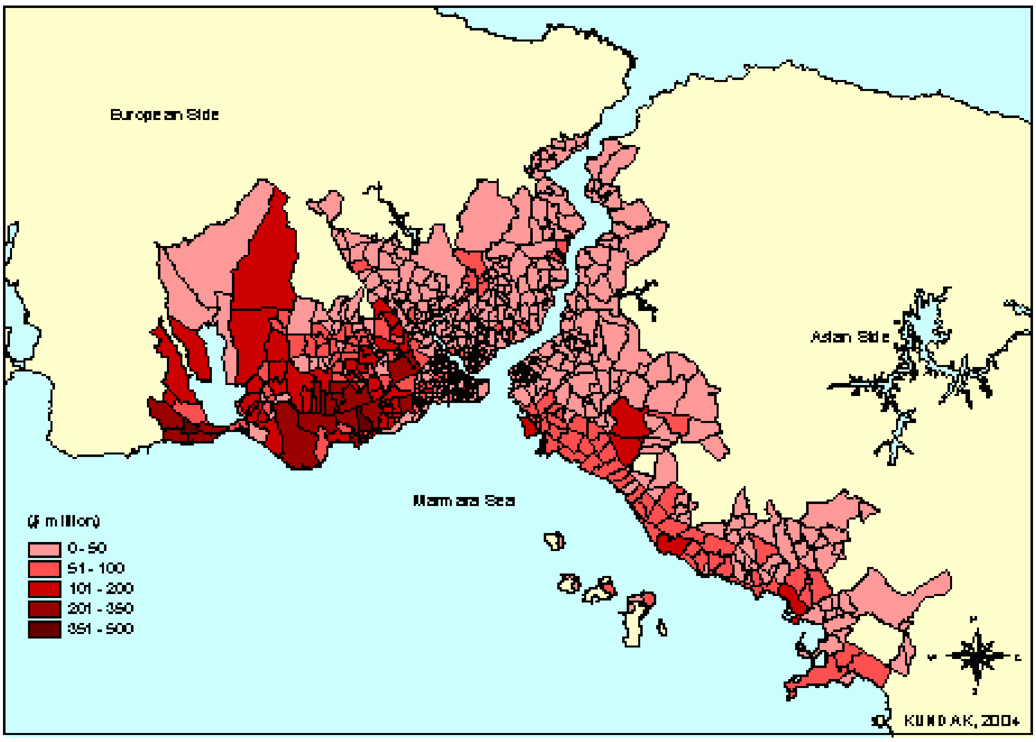

Figure 4. Total Damage Cost (M=7.7)

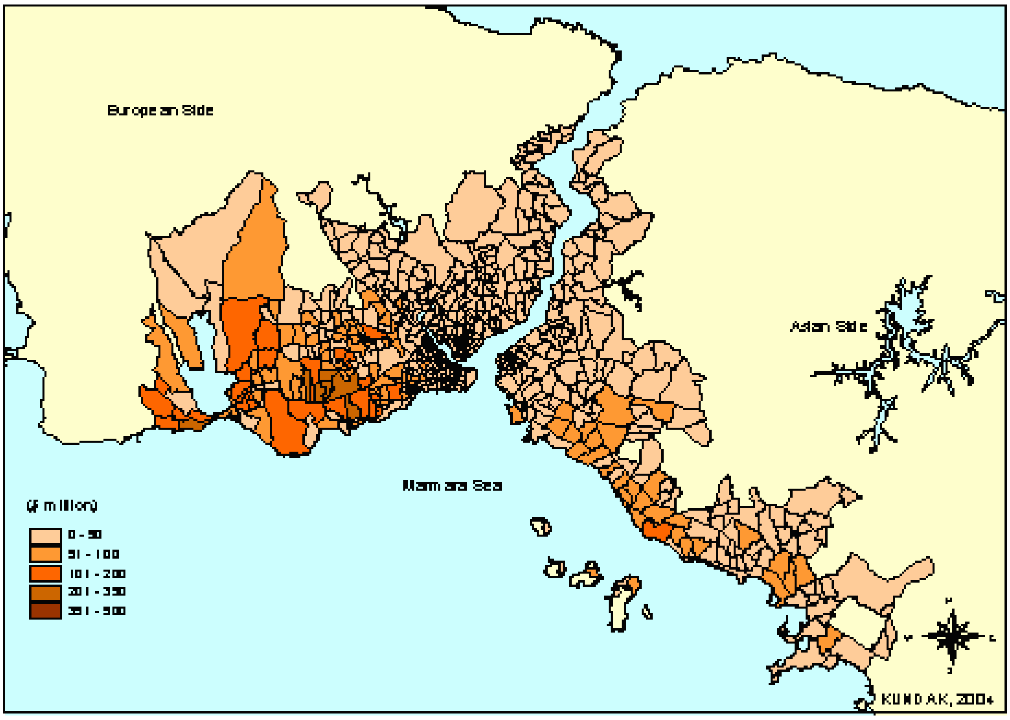

Figure 5. Total Damage Cost of Housing Units (M=7.7)

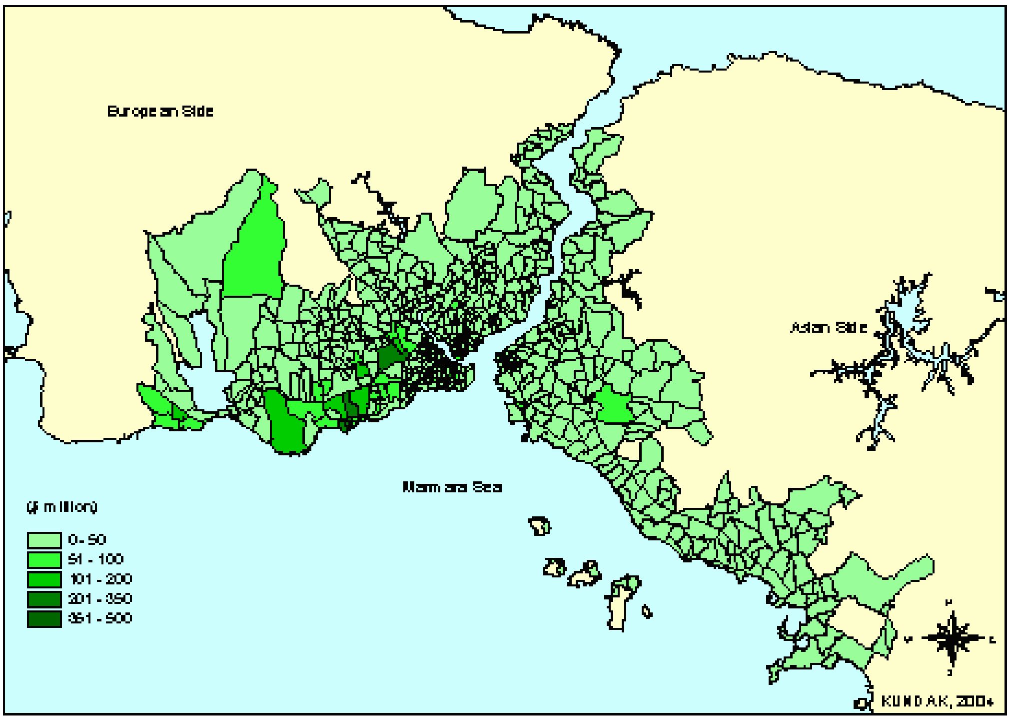

Figure 6. Total Damage Cost From Interruption of Business Activity (M=7.7)

In comparison with the most probable-case scenario, in the worst-case, total cost increases just $3.03 billion. However, if damage ratios of these two scenario are compared, the second one can create mega-disaster with its damages on urban facilities, infrastructure, and industrial areas. Furthermore, comparing with the GDP of Istanbul in 2001 which was around $31 billion, these estimated values are rather high if one consideres damages on lifelines, probable secondary hazards damages (fire, flood) etc. are excluded.

5. Conclusion

Natural disasters, especially earthquakes, can be devastating to human activities, to social organisations at every level and to economic life. Economic losses by severe earthquakes can cause long-term reductions in the growth of a nation's economy. In order to estimate probable future losses in earthquake-prone regions, output of loss estimation techniques are the powerfull tools as input of planning process.

The expected economic losses represented in this study include only housing and work places indicators and are equivalent to nearly 20% of country's GDP. Other losses in infrastructure, facilities etc. can increase these costs. 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 İstanbul require long time and big budget. Moreover, achievement of these attemps requires a well organized control and feedback system as well.

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