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Economic Impacts of Expected Istanbul Earthquake: Scenario Generation

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Abstract: It is difficult to make precise estimations about the time, location, and magnitude of earthquakes which can cause significant consequences such as massive casualties and economic losses. Although the earthquakes cannot be prevented, minimization of losses can be achieved with effective disaster management. In this study, four most likely scenarios that are put forward by the geological engineers and scientists are evaluated to illustrate the potential impacts of a possible earthquake. Therefore, effects of an earthquake on physical damage, sectoral growth and post-earthquake government expenditures, tax revenues, investments, imports, and exports are numerically estimated. Additionally, since Istanbul has an intense economic relations and workforce flow beyond its borders, it is evaluated as a whole with Kocaeli and Tekirdağ provinces. The impact of the earthquake is privatized on the basis of Istanbul, Kocaeli and Tekirdağ districts. Considering the location of the fault lines and length of breaks, it is thought that different districts would be affected by the earthquake in different degrees, and impacts of scenarios are created in this direction. Damage rates in different districts due to different magnitudes are predicted by taking 17 August 1999 Izmit Bay Earthquake as a basis. As a result of this study, the damage rates of the building stock and industrial facilities, number of casualties, sectoral and expenditure change rates in the districts of Istanbul, Tekirdağ and Kocaeli are determined. In addition, the change rates in physical, sectoral, and expenditure areas are also reflected on the rest of Türkiye. Thus, the results obtained from the scenarios will help to generate certain policy strategies after the earthquake and contribute to reducing economic, social, and physical damage.

Key Words: Natural disaster, Earthquake, Scenario analysis, Disaster economics, Loss estimation

Introduction

Throughout history, earthquakes caused both losses of life and severe economic damage. Due to its nature, it is not possible to predict the time and the location of earthquakes. However, it is possible to minimize the losses

by estimating the impacts of an earthquake. To minimize the losses and make effective plans, generating several earthquake scenarios is important since they picture what kind of situation can be faced in a possible disaster event (Lednická, 2006; Hempen, 2007). In other words, developing earthquake scenarios and analyzing the results have a major role to mitigate the damages and taking precautions. Additionally, scenario generations are critical for determining the policies specifically for post-earthquake recovery processes (Rodgers et. al.,2020).

After the 17 August 1999 earthquake in Istanbul, it is known that a major seismic tension has accumulated under the Marmara Sea and a massive earthquake is being awaited for Istanbul (Bohnhoff et al., 2013; Lange et al., 2019; Şimşek et.al.,2021). Therefore, it becomes vital to understand and analyze the outcomes of an expected Istanbul earthquake with the help of possible scenarios. This paper investigates the degree of damage and impacts of a possible earthquake based on the four most likely scenarios developed by geological engineers and scientists. According to these four scenarios, the fault segments with a high risk of break in Istanbul are evaluated. Additionally, although this earthquake is mainly expected to occur in Istanbul, it is not surprising to expect its effects beyond its borders. Therefore, Istanbul is evaluated as a whole with its surrounding provinces Kocaeli and Tekirdağ since it has direct economic relations with these two provinces.

Last but not least, the analysis is performed at the district level for Istanbul, Kocaeli, and Tekirdağ to illustrate the impacts of the scenarios, namely, where the earthquake occurred and at what magnitude. It can be noted that the location and the magnitude of an earthquake are one of the first selected factors while predicting the damages (Mader,1994). Therefore, considering different earthquake magnitudes, in other words, earthquake shocks at the district level gives more realistic results while evaluating the impact of the scenarios. According to the results of scenario evaluations, physical damages, and economic factors are decided to examine. In detail, the number of dead and injured people, damaged buildings and industrial facilities, post-earthquake changes for eleven sectors, and government expenditures, tax incomes, investments, import, and export amounts are estimated numerically. After that, these results are reflected in the Rest of Türkiye to examine the effects in a wider context.

Literature Review

Scenario generations for disaster management, particularly for earthquakes have been studied for years (Mader et.al.,1994; Villacis et al.,2000; Isık et al.,2019). These scenarios are mainly used to assess the risks after an earthquake and determine the government policies or emergency actions (Durukal et.al.,2002, Özmen 2002; Erdik, 2003; Young et. al.,2019). Some of these studies focused on earthquake scenarios in developing countries rather than industrialized ones since the scenarios are highly dependent on whether the earthquake happened in economically developed or developing countries (Erdik, 1994; Villacís et al.,1997). On the other hand, in literature, most of the articles about scenario generation and loss estimation in Türkiye are focused on the Marmara region (Durukal et.al., 2002; Erdik et.al.,2008, Strasser et.al.,2008, Demircioglu et al.,2009). It is reasonable since the economic activities are mostly concentrated in the Marmara region and population density is high. Additionally, an earthquake with a magnitude of 7 or more is expected with a %2 annual probability on the main Marmara fault line (Durukal et.al, 2008).

It is known that the first earthquake damage scenario is developed by the Research Division of the General Directorate of the Ministry of Public Works and Settlement based on 1894 earthquake results (Erdic et al.,1994). However, in this study, Istanbul is not considered specifically, in other words, the global damage in the region is predicted rather than the whole of Istanbul. Thus, Erdic et al. (1994) investigated a scenario earthquake with 7-7.5 Mw magnitude and predicted the direct losses in Istanbul. Additionally, he mentioned the earthquake disaster master plan which is prepared for Istanbul with two scenarios; medium and high-intensity earthquakes with 100 and 500 years return periods. Similarly, Özmen (2002) generated an earthquake scenario in Istanbul with a magnitude of 7.8 Mw which occurs at the nearest part of the Northern Boundary Fault where the surface rupture length is accepted as 140 km. Then, the number of buildings with severe, moderate, and minor damage is computed by using the damage estimates in the regions which are affected by different severities. In addition, the expected number of dead and injured people is also determined. Durukal et.al., (2002) examined the average damage rates for industrial facilities to analyze the possible industrial losses during the Kocaeli earthquake. The mean damage ratio for industrial enterprises is determined as %3 for 7 Mw, %8 for 8 Mw, and %20 for 9 Mw magnitude earthquake. Moreover, the loss ratios for different sectors are predicted by considering the equipment and machinery losses in case of a 9 Mw magnitude earthquake. After, Durukal et.al., (2008) used this information to predict the expected industrial losses in Istanbul. In their article, while the overall loss for industrial buildings is found as between 6 and 8%, the business interruption for chemical, textile, and automotive sectors is computed as 50, 30, and 20%, respectively. Furthermore, according to Erdik et.al. (2011),

2%-4% of the buildings are expected to have severe damage while %9-%15 have moderate and 20%-34% have light damage in Istanbul in the case of a 7.25 Mw earthquake.

The most recent report that predicts the overall loss for an expected Istanbul earthquake is prepared by the prepared by the Kandilli Observatory and Earthquake Research Institute. According to their findings, if an earthquake occurs at night with a magnitude of 7.5 Mw, there will be 17% of moderate or higher-level damaged buildings and approximately 14,150 people will lose their life. Additionally, they showed that while the financial losses due to structural damage can be expected to be around 68 billion TL, non-structural damages will be around 120 billion TL. In addition, according to TÜSİAD and TURKONFED ‘s report 25 to 300 billion dollars of economic damage is expected in case of a 7.5 Mw scenario earthquake.

Methodology

The study first provides the estimations about the physical, sectoral, and economic variables for Istanbul, Kocaeli, and Tekirdağ districts through numerical analysis. Secondly, the most likely expected scenarios for the Istanbul earthquake are explained and earthquake shocks are created for each district to illustrate the impact of four determined scenarios. Finally, post-earthquake results regarding the physical damage, and sectoral and economic changes are shown for Istanbul, Tekirdağ, and Kocaeli provinces. Additionally, analysis is performed for the remaining provinces of Türkiye to show how they will be affected in case of an expected Istanbul earthquake which will occur in the heart of the country.

Pre-Earthquake Estimations

The physical variables which can be considered as population, the number of residential buildings, and industrial facilities are determined separately for Istanbul, Kocaeli, and Tekirdağ provinces at the district level. The required data are obtained from TURKSTAT and the Ministry of Industry for the year 2020. However, the data for number of buildings is not available for the districts of Tekirdağ and Kocaeli provinces. Therefore, due to its closeness and similar regional characteristics, the number of buildings in Kocaeli province is assumed by considering the Tuzla district. Likewise, the Büyükçekmece district is used for examinations to represent Tekirdağ province.

Secondly, the size of the eleven sectors for the districts is predicted by using Gross Domestic Product (GDP) data in terms of economic activity. In that sense, the GDP by province is allocated on the basis of population, the number of buildings, or industrial facilities to these sectors for each district. For instance, to determine the size of the construction sector in a particular district, the number of buildings in that district is divided by the total number of buildings in the province to which it belongs. Then, this calculated ratio is used to distribute the relevant province's GDP to the relevant district. Similarly, economic variables such as government expenditures, tax incomes, and investments are obtained by applying the same approach. On the other hand, export and import amounts are derived from the Province Industry Status Reports for Istanbul, Tekirdağ, and Kocaeli. These shares are used to predict the import and export values for the districts.

Scenario Generation

The four most likely scenarios which are developed by the experts are studied and listed as follows:

Scenario 1: The magnitude of 6.9 earthquake caused by a 37 km fault break in Gulf.

Scenario 2: The magnitude of 7.4 earthquake caused by a 108 km fault break in the Central Marmara Basin.

Scenario 3: The magnitude of 7.5 earthquake caused by a 119 km fault break which starts in the Gulf and goes through the middle of the Marmara Sea.

Scenario 4: The magnitude of 7.7 earthquake occurred by a 174 km fault break that started from the Gulf and reached the end of the Marmara Sea, rupturing the entire Central Marmara Basin.

According to the impact of scenarios, the earthquake shocks are created for each district of Istanbul, Kocaeli, and Tekirdağ. These shocks vary between 6 to 10 in terms of Mercalli magnitude. While determining the

different magnitudes for the districts in line with scenarios, the closeness of the districts to fault lines and the Marmara Sea as well as their resistance to the earthquake are considered. For instance, if Scenario 2 occurs, the coastline of Istanbul is expected to be severely affected. Since the distance of the fault breaks to city center is approximately 20 kilometers, the coastal districts with this proximity will experience the earthquake more severely.

To analyze the impacts of an earthquake with varying magnitudes, an Excel file is prepared. By using this file, it is possible to observe how the damage caused by an earthquake will change as the magnitude of an earthquake changes on a district basis. Since the different magnitudes directly affect the number of damaged buildings, industrial facilities, and the number of casualties, outputs of an earthquake such as physical damages, changes in sector sizes, and in other economic variables can be observed easily with the help of this excel.

In the study, firstly, the ratios for the physical damages are estimated. The number of severely, moderately, and slightly damaged, and undamaged buildings as well as the number of casualties based on different Mercalli magnitudes are extrapolated by using the data from Özmen (2000)'s study. The building damage ratios for the regions affected by the 17 August 1999 Izmit Bay earthquake at different Mercalli magnitudes are shown in Table 1 below. Besides that, severely, moderately, and slightly damaged, and undamaged ratios for industrial facilities are obtained by multiplying the building damage ratios given in Table 1 by 0.75. The coefficient of 0,75 is used for this prediction since the earthquake resistance is higher for the industrial facilities than the residential buildings (T.B.D.,2018).

Subsequently, ratios for the casualties are predicted regarding different Mercalli magnitudes. For instance, ratios for the number of dead people are calculated by multiplying the ratio of severely damaged buildings for each magnitude with 26%. It can be noted that, 26% is obtained by dividing the number of dead people in 17 August 1999 Izmit Bay to the number of severely damaged buildings. Similar calculations are also performed to assume the ratios for the number of injured people. Firstly, the coefficient of 2.51 is found by dividing the number of injured people to the number of dead people in 17 August 1999 Izmit Bay Earthquake, then, it is multiplied with the severely damaged buildings' ratio.

Table 1. Damage ratios for the buildings affected by the 17 August 1999 Izmit Bay Earthquake at different magnitudes (Özmen,2000)

Mercalli Magnitude	Severely Damaged Buildings (%)	Moderately Damaged Buildings (%)	Slightly Damaged Buildings (%)	Undamaged Buildings (%)
6	0,04	0,22	0,24	99,50
7	0,91	2,67	2,59	93,83
8	2,82	4,41	5,31	87,46
9	15,7	18,16	22,75	43,39
10	33,06	15,29	19,14	32,51

Table 2. Damage ratios for the industrial facilities and casualties affected by the 17 August 1999 Izmit Bay Earthquake at different magnitudes

Mercalli Magnitude	Severely Damaged Industrial Facilities (%)	Moderately Damaged Industrial Facilities (%)	Slightly Damaged Industrial Facilities (%)	Undamaged Industrial Facilities (%)	Number of Deaths (%)	Number of Injuries (%)
6	0,03	0,17	0,18	99,63	0,01	0,10
7	0,68	2,00	1,94	95,37	0,24	2,29
8	2,12	3,31	3,98	90,60	0,73	7,09
9	11,78	13,62	17,06	57,54	4,08	39,49
10	24,80	11,47	14,36	49,38	8,60	83,15

Post-Earthquake Estimations

According to the calculated ratios given in the previous section, the post-earthquake values of physical, sectoral, and economic variables are estimated at the district level for different earthquake magnitudes. In other words, the current number of buildings and industrial facilities in the districts are multiplied by the ratios provided in

Tables 1 and 2 to illustrate the impact of a possible earthquake. Similarly, the number of deaths and injuries is obtained by multiplying the current population in the districts with the relevant ratios.

On the other hand, the district-based sectoral sizes are found by considering the post-earthquake values of the number of buildings, industrial facilities, and/or population. In addition, the current status of the sectors in relevant districts is taken into account for the calculations. For instance, while predicting the agriculture, forestry, and fisheries sector size of each district, the agricultural land size of the districts is accounted in for calculations ("Agricultural land size by sufficient income in Türkiye provinces and districts," n.d.). The areas with larger agricultural land sizes are thought to be more affected by an earthquake, and the importance weight coefficients in the formulas are determined accordingly.

Then, post-earthquake expenses, taxes, and changes in trade are examined. The government expenditures are estimated by weighting the number of severely and moderately damaged buildings and industrial facilities. Then, these ratios are multiplied by the pre-earthquake value of government expenditures. In the same manner, tax revenues, investments exports, and imports are calculated. In these calculations, an increase in government expenditures due to the government's earthquake relief efforts, and a decrease in tax revenues are assumed. Besides these, import and export amounts are figured out. Likewise, the calculations are performed by using pre and post-earthquake sector values and their importance weights in related districts.

Finally, the sectoral and economic impact of an Istanbul earthquake is demonstrated on a provincial basis for the Rest of Türkiye. Incidentally, the pre-earthquake values for the remaining provinces are obtained from TURKSTAT for the year 2020. To illustrate the impact, percentage changes in sectors and economic variables covering Istanbul, Kocaeli, and Tekirdağ provinces are calculated using their pre- and post-earthquake values. Therefore, İstanbul, Kocaeli, and Tekirdağ are evaluated as a whole while analyzing the effects of an earthquake on the Rest of Türkiye. Subsequently, the earthquake impact levels for the remaining provinces are determined by considering the percentage intervals which the calculated percentage changes fall into. Percentage intervals are defined as % 0-10, %10-20, %20-30, %30-40, and %40-50. Therefore, depending on which interval the calculated percentage change falls into, a corresponding impact level is assigned in an Excel file with the help of if functions. Then, the post-earthquake values are found by multiplying these impact levels with pre-earthquake values. For instance, if the percentage change in the agriculture sector is determined between 40% and 50%, then the sectoral impact level of the province is determined, accordingly. As a result, the post-earthquake agriculture sector size for the province is computed regarding these impact levels. Additionally, in that case, it is not surprising to expect a higher decrease the in agriculture sector for the remaining provinces.

Results and Discussion

This study evaluates four potential scenarios proposed by geological engineers and scientists to illustrate the expected social and economic impacts of an earthquake expected to occur in the Istanbul region. Due to Istanbul's economic and geological importance to its neighbours, the region is evaluated as a whole with Tekirdağ and Kocaeli.

Scenario I

In the first scenario, it is assumed that an earthquake with a magnitude of 6.9 occurred as a result of a fracture with a length of 37 km in the Gulf. Table 3 shows the expected damages for the buildings, industrial facilities, and the total of all constructions in the Istanbul region. While 92.58% of the buildings are expected to stay undamaged, this ratio is 95.99% for industrial facilities.

Table 3. Expected damages for constructions in Istanbul region for scenario 1

Construction Type	Severely Damaged	Moderately Damaged	Slightly Damaged	Undamaged
Buildings	29209	38339	46168	1420465
Industrial Facilities	307	454	528	30840
Total	29516	38793	46696	1451305

Figure 1 shows the casualties and migration. Based on this figure, it can be inferred that an increase in migration from the affected region to other cities is expected due to the extensive damage to buildings.

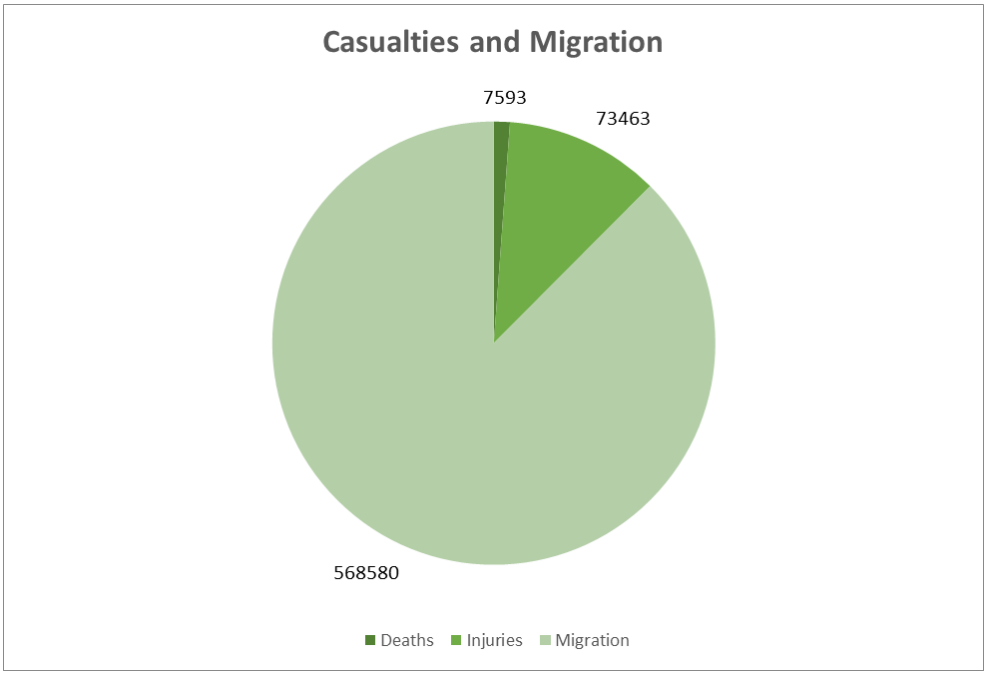

Figure 1. Expected casualties and migration in Istanbul region for scenario 1

As mentioned before, for this study, Türkiye is divided into two regions, Istanbul region and the Rest of Türkiye. Considering Istanbul's significant role in both the social and economic aspects of Türkiye, it is anticipated that the impacts of such an earthquake extend beyond the borders of the region and have an effect on the entire country. In Table 4, the changes in some economic variables in both regions after the earthquake are demonstrated. Since the government expenditures are transferred to the region, it is expected that the expenditures in the disaster region will increase. However, for a certain period, people affected by the earthquake will not be charged any taxes, which results in a decrease in tax revenues in that region. Furthermore, it is expected that investments in the region increases compared to the rest of the country.

Table 4. Expected change rates in economic variables for Istanbul region the and rest of Türkiye for scenario 1

	Change in Istanbul Region (%)	Change in Rest of Türkiye (%)
Government Expenditures	3.139	-0.431
Tax Revenues	-5.029	0
Investments	1.524	-0.444

Table 5 shows the changes in the total of sectors, imports, and export for the Istanbul region, the Rest of Türkiye, and the country as a whole. Even though there are declines in those variables in the Istanbul region, the earthquake does not have a notable impact on the rest of the country. Table 5 provides evidence that the earthquake has a greater impact on exports than imports.

Table 5. Expected change rates in sectors, imports and exports in Türkiye for scenario 1

	Change in Total of Sectors (%)	Change in Import (%)	Change In Export (%)
Istanbul Region	-3.103	-1.568	-2.058
Rest of Türkiye	0	0	0
Türkiye	-1.112	-1.011	-1.154

In this study, eleven different sectors are evaluated. Table 6 provides a general overview of the effects of the disaster on sectors, whereas Table 6 shows it in a more detailed manner by dividing it into eleven subcategories. From the table, it can be seen that the changes in the Istanbul region vary depending on the sector. Some sectors experience a substantial decrease, while others experience a more moderate one. Since this scenario is based on a relatively small-scale earthquake, the rest of Türkiye is not affected by it on the sector level.

Table 6. Expected change rates in subcategories of sectors in Istanbul region and the rest of Türkiye for scenario 1

	Change in Istanbul Region (%)	Change in Rest of Türkiye (%)
Agriculture, Forestry and Fishing	-1.577	0
Manufacturing, Mining, Quarrying and Other Industries	-2.060	0
Manufacturing Industry	-3.431	0
Building	-2.081	0
Wholesale And Retail Trade, Transportation And Storage, Accommodation And Food Service Activities	-5.682	0
Information and Communication	-0.615	0
Finance and Insurance Activities	-1.630	0
Real Estate Activities	-2.439	0
Professional, Scientific, Technical, Administrative and Support Service Activities	-1.569	0
Public Administration and Defense, Education, Human Health and Social Service Activities	-1.304	0
Other services	-0.734	0

Scenario II

In the second scenario, an earthquake with a magnitude of 7.4 caused by a 108 km fault break in the Central Marmara Basin is evaluated. The physical impacts of the earthquake are displayed in Table 7 based on the damage to constructions in the region. It is expected that 83.69% and 84.69% of the constructions will be undamaged for buildings and industrial facilities, respectively. In this scenario, there is not a vital difference depending on the construction type.

Table 7. Expected damages for constructions in Istanbul region for scenario 2

Construction Type	Severely Damaged	Moderately Damaged	Slightly Damaged	Undamaged
Buildings	93641	70588	85929	1284023
Industrial Facilities	1769	1411	1737	27212
Total	95410	71999	87666	1311235

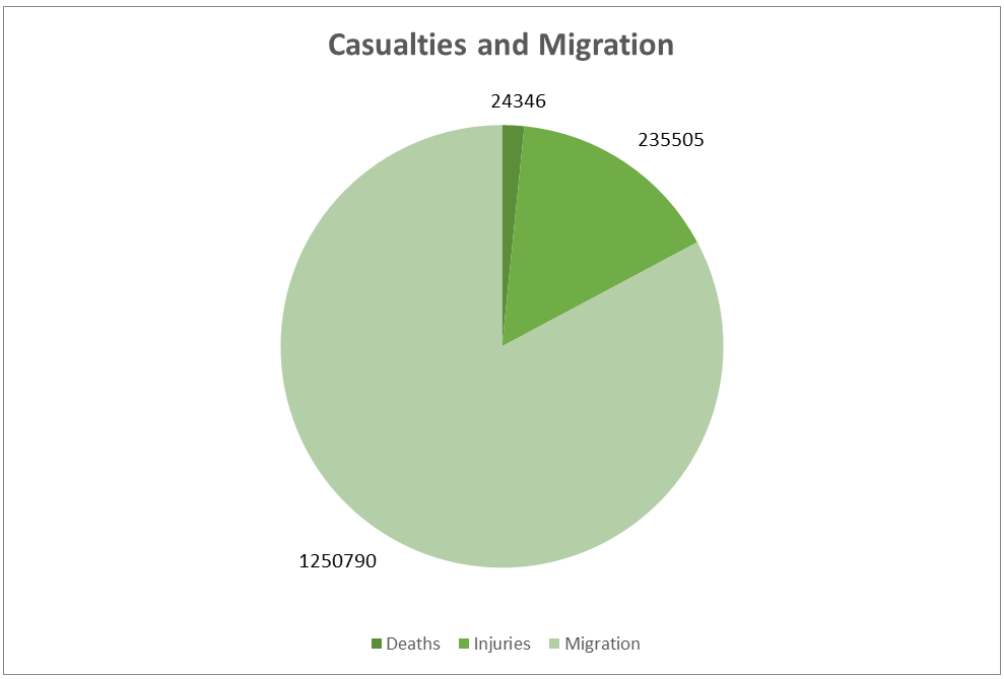

Figure 2. Expected casualties and migration in Istanbul region for scenario 2

In Figure 2, the social impacts are presented. Due to damage to the buildings and industrial facilities, local people are likely to migrate to other regions. Moreover, because of its scale compared to the first scenario, the expected casualties are relatively high in this scenario The economic impacts of the earthquake can be seen in Table 8. Though the Rest of Türkiye is not affected significantly, there is a substantial increase in investments and government expenditures for the Istanbul region.

Table 8. Expected change rates in economic variables for Istanbul region and the Rest of Türkiye for scenario 2

	Change in Istanbul Region (%)	Change in Rest of Türkiye (%)
Government Expenditures	7.390	-0.431
Tax Revenues	-9.452	0
Investments	7.923	-0.444

Table 9 and Table 10 display the effects on total sectors and the subcategories respectively. In this case, the decline is more significant compared to the first scenario. Additionally, for some sectors, the impacts surpassed the borders of Istanbul, which causes a decline in some sectors in the Rest of Türkiye.

Table 9. Expected change rates in sectors, import and exports in Türkiye for scenario 2

	Change in Total of Sectors (%)	Change in Import (%)	Change In Export (%)
Istanbul region	-9.720	-8.008	-7.243
Rest of Türkiye	-0.611	0	0
Türkiye	-3.876	-5.163	-4.061

Table 10. Expected change rates in subcategories of sectors in Istanbul region and the Rest of Türkiye for scenario 2

	Change in Istanbul Region (%)	Change in Rest of Türkiye (%)
Agriculture, Forestry And Fishing	-2.692	0
Manufacturing, Mining, Quarrying and Other Industries	-4.619	0
Manufacturing Industry	-6.193	0
Building	-8.918	0
Wholesale And Retail Trade, Transportation And Storage, Accommodation And Food Service Activities	-18.229	-2.451
Information and Communication	-7.127	0
Finance and Insurance Activities	-12.658	-2.530
Real Estate Activities	-10.494	-2.208
Professional, Scientific, Technical, Administrative and Support Service Activities	-7.319	0
Public Administration and Defense, Education, Human Health and Social Service Activities	-3.557	0
Other services	-2.783	0

Scenario III

In the third scenario, the evaluation is made based on an earthquake with a magnitude of 7.5 earthquake caused by a 119 km fault break which starts in the Gulf and goes through the middle of the Marmara Sea. This scenario examines a relatively larger-scale earthquake. The damages on the different types of constructions are presented in Table 11. The study indicates that 74.37% of the buildings will be undamaged, while this ratio is 79.45% for the industrial facilities. It can be inferred from the table that the disaster has a more catastrophic impact on buildings compared to industrial facilities.

Figure 3 demonstrates the casualties which are expected to be relatively higher than the other two scenarios examined. In addition, when taken into account together with Table 11, it is evident that due to the damage in

constructions, people resident in the area are likely to relocate to other cities for both residential and economic purposes.

Table 11. Expected damages for constructions in Istanbul region for scenario 3

Construction Type	Severely Damaged	Moderately Damaged	Slightly Damaged	Undamaged
Buildings	145765	110493	136915	1141008
Industrial Facilities	2395	1878	2328	25527
Total	148160	112371	139243	1166535

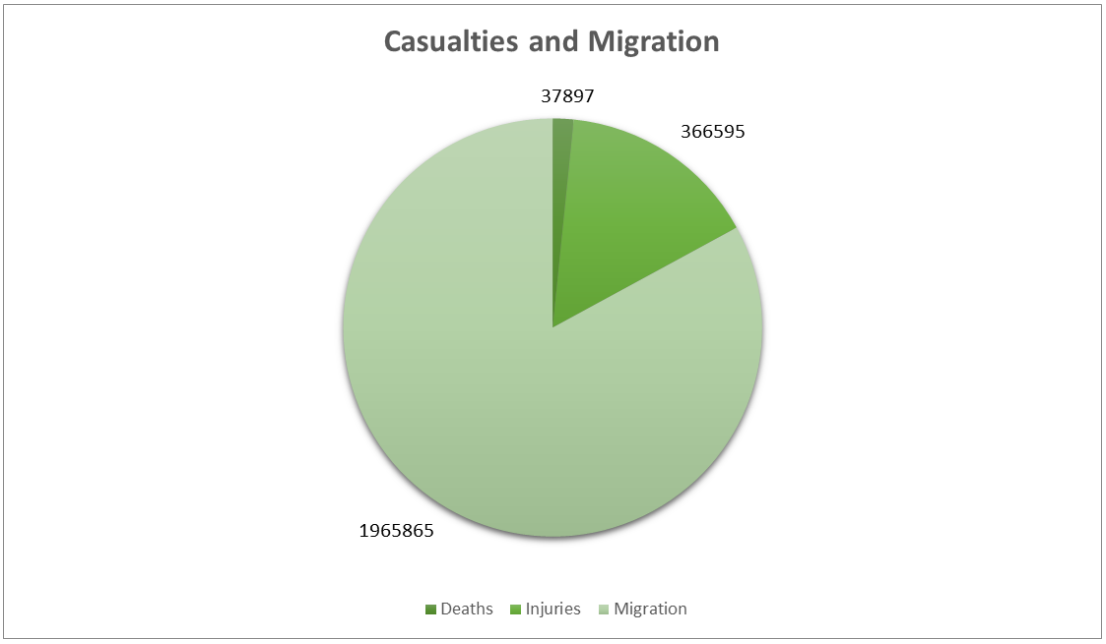

Figure 3. Expected casualties and migration in Istanbul region for scenario 3

According to Table 12, the Istanbul region is significantly affected by the earthquake with huge increases in government expenditures and investments in the disaster region. Moreover, in this scenario, the Rest of Türkiye is significantly affected by the earthquake on the economic level.

Table 12. Expected change rates in economic variables for Istanbul region and the rest of Türkiye for scenario 3

	Change in Istanbul Region (%)	Change in Rest of Türkiye (%)
Government Expenditures	11.585	-1.875
Tax Revenues	-15.895	-3.084
Investments	10.414	-1.951

Based on the results presented in Table 13 and Table 14, there is a significant decrease in the sectoral variables for the Istanbul region. Depending on the intensity of the earthquake, in this case, the changes in the Rest of Türkiye is also notable, specifically in some sectors.

Table 13. Expected change rates in sectors, imports and exports in Türkiye for scenario 3

	Change in Total of Sectors (%)	Change in Import (%)	Change in Export (%)
Istanbul region	-13.814	-10.311	-9.908
Rest of Türkiye	-1.264	-2.717	0
Türkiye	-5.763	-7.613	-5.555

Table 14. Expected change rates in subcategories of sectors in Istanbul region and the rest of Türkiye for scenario 3

	Change in Istanbul Region (%)	Change in Rest of Türkiye (%)
Agriculture, Forestry And Fishing	-4.804	0
Manufacturing, Mining, Quarrying and Other Industries	-7.114	0
Manufacturing Industry	-9.949	0
Building	-12.112	-2.299
Wholesale And Retail Trade, Transportation And Storage, Accommodation And Food Service Activities	-25.698	-5.569
Information and Communication	-9.068	0
Finance and Insurance Activities	-15.785	-2.530
Real Estate Activities	-14.388	-2.208
Professional, Scientific, Technical, Administrative and Support Service Activities	-9.798	0
Public Administration and Defense, Education, Human Health and Social Service Activities	-5.203	0
Other services	-3.790	0

Scenario IV

The last scenario is generated based on an earthquake with a magnitude of 7.7 earthquake caused by a 174 km fault break that started from the Gulf and reached the end of the Marmara Sea, rupturing the entire central Marmara Basin. This scenario demonstrates the most destructive outcomes among the four scenarios. In Table 15, the impacts of the earthquake on different types of constructions are presented. According to that, only 63.60% of the buildings are expected to be stayed undamaged, while for the industrial facilities, 69.59% of them stay undamaged.

Table 15. Expected damages for constructions in Istanbul region for scenario 4

Construction Types	Severely Damaged	Moderately Damaged	Slightly Damaged	Undamaged
Buildings	236888	144107	177462	975724
Industrial Facilities	4350	2434	2983	22361
Total	241238	146541	180445	998085

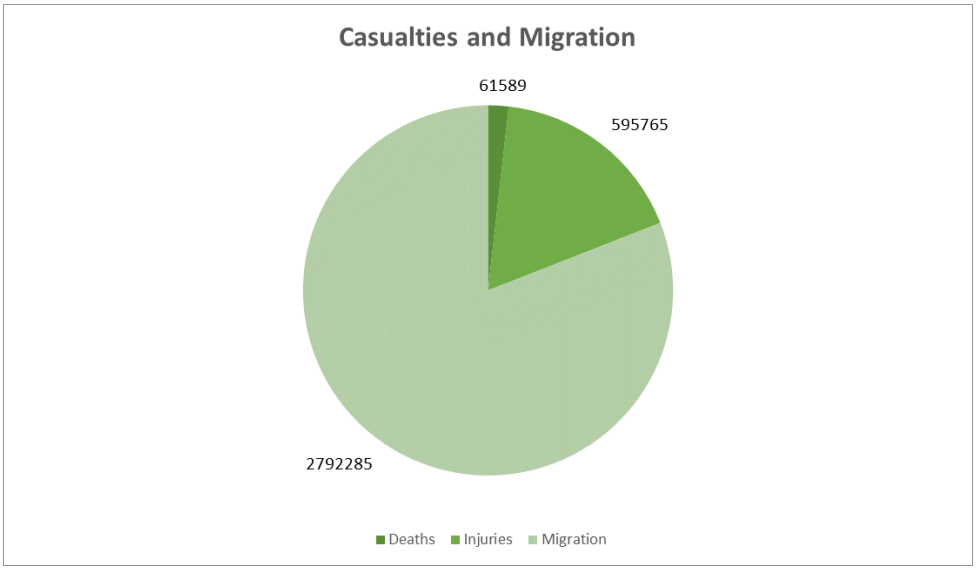

Figure 4. Expected casualties and migration in Istanbul region for scenario 4

In Figure 4, the expected casualties and the people likely to migrate are demonstrated. Since this is the scenario that is expected to cause more devastating outcomes, the casualties are substantially higher compared to others. Due to the damage to both residential and industrial constructions, most of the residents in the area are expected to relocate to a new region which results in a higher migration rate. Since this scenario studies a larger-scale earthquake, its impacts are expected to be more profound. Such an earthquake with this intensity is predicted to have a significant impact throughout the country. The impacts on some economic variables are presented in Table 16.

Table 16. Expected change rates in economic variables for Istanbul region and the rest of Türkiye for scenario 4

	Change in Istanbul Region (%)	Change in Rest of Türkiye (%)
Government Expenditures	18.847	-1.875
Tax Revenues	-25.313	-6.538
Investments	17.787	-1.951

Due to the magnitude of impact in this scenario, the most significant changes occur in this one which can be inferred by the huge decreases in economic variables. The values of sectors are critically decreased for both the Istanbul region and the Rest of Türkiye. Also, there are notable decreases in both imports and exports for the whole country. The findings can be observed in Table 17 and Table 18.

Table 17. Expected change rates in sectors, imports and exports in Türkiye for scenario 4

	Change in Total of Sectors (%)	Change in Import (%)	Change In Export (%)
Istanbul region	-21.869	-15.555	-14.642
Rest of Türkiye	-4.591	-2.717	-2.746
Türkiye	-10.784	-10.995	-9.416

Table 18. Expected change rates in subcategories of sectors in Istanbul region and the Rest of Türkiye for scenario 4

	Change in Istanbul Region (%)	Change in Rest of Türkiye (%)
Agriculture, Forestry And Fishing	-8.916	0.000
Manufacturing, Mining, Quarrying and Other Industries	-11.005	-2.781
Manufacturing Industry	-14.085	-2.951
Building	-17.990	-2.299
Wholesale And Retail Trade, Transportation And Storage, Accommodation And Food Service Activities	-41.066	-16.093
Information and Communication	-17.095	-3.330
Finance and Insurance Activities	-27.498	-5.681
Real Estate Activities	-22.034	-5.227
Professional, Scientific, Technical, Administrative and Support Service Activities	-16.672	-2.628
Public Administration and Defense, Education, Human Health and Social Service Activities	-8.185	0.000
Other services	-6.131	0.000

Conclusion

In this study, four different scenarios suggested by the experts of the subject were examined to illustrate the impacts of an earthquake on physical and economic variables for the expected Istanbul earthquake. These scenarios include four different earthquakes, ranging from relatively smaller to larger scales, resulting from the rupture of different fault lines. Due to Istanbul's economic relations with its neighbours Tekirdağ and Kocaeli, it is considered as a whole with these two cities, and the study is carried out in this direction.

It is known that depending on the location and the length of the rupture, the effects of the earthquake vary from district to district. Thus, for each district different intensity levels are assigned and the Mercalli scale is used for

this purpose. When the findings are evaluated, in Scenario 1 the impact on both physical and economic variables is relatively small in the Istanbul region whereas the rest of the country is not affected substantially. However, in Scenario 4 which represents a relatively larger-scale earthquake, it causes severe economic and social impacts in the Istanbul region, while having significant effects in the Rest of Türkiye, especially on the economic level.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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