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Probabilistic earthquake hazard assessment for Ankara and its environs

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Abstract: The capital and the second largest city of Turkey, Ankara, is generally considered to be safe in terms of seismic activities and earthquake hazard. However, recent studies and earthquakes experienced in the region showed that Ankara is not indeed seismically safe. As the number of studies on Ankara's seismic hazard increases, the number of scientists who claim that the earthquake hazard in Ankara is higher than expected also increases. However, to date no detailed analysis has been undertaken as to the earthquake hazard facing Ankara. This study has compiled data from the earthquake catalogues available in Turkey and employed the latest knowledge available to produce an Ankara-specific earthquake catalogue. Probabilistic seismic hazard analysis of the unified data was then used to produced peak ground acceleration (PGA) values for 5%, 10%, 20%, and 40% probability of exceedance over a 50-year return period. The PGA values at main rock sites were determined using the most appropriate attenuation relationship. These show an exceedance probability of 10% over a 50-year return period to range from 0.20 g to 0.25 g for the Ankara provincial districts of Ayaş, Çankaya, Etimesgut, Sincan, and Yenimahalle; from 0.25 g to 0.30 g for Altındağ, Gölbaşı, Keçiören, and Mamak; and from 0.30 g to 0.35 g for Akyurt, Çubuk, Elmadağ, and Kazan.

Key words: Ankara, earthquake, hazard, peak ground acceleration, probability, seismicity

1. Introduction

Ankara is situated in the Central Anatolia Region (Figure 1) with a population of 4,842,136 in 2012, which is equivalent to 6.4% of the total population of Turkey. It is the second largest city in Turkey. There are 25 districts in Ankara and 96% of Ankara's population lives within the investigated area.

The city is surrounded by 4 main fault lines: the North Anatolia Fault Zone (NAF) in the north, the Ezinepazarı Fault in the east, the Tuzgölü Fault Zone in the south-east, and the İnönü-Eskişehir Fault Zone in the west and south-west. These faults have the potential to create an earthquake with magnitudes of greater than 7.0 on the Richter scale ($M \geq 7.0$). This is a very important seismic threat to Ankara. In addition to these main faults, there are numerous active faults within the province and its surroundings, including the city centre. These additional active faults can cause small- to medium-scale earthquakes ($5.0 < M < 6.0$) with possible losses.

Few people believe that there is a seismic hazard in Ankara as the city has not experienced large devastating earthquakes in recent history. However, the active fault lines surrounding the city clearly pose a substantial threat, which this study set out to explore in detail. The Van earthquake of 23 October 2011 resulted in a strong political will for 'urban transformation'. It is also well known that most of the current building stock in Turkey is highly vulnerable to earthquakes and needs to be reconstructed or retrofitted. The probabilistic results published in this study can also be used by policymakers to prepare efficient hazard mitigation plans for Ankara. This paper provides background information on existing studies and details of the region. Next, the methodology is presented. Results and suggestions conclude the paper.

Ankara is situated in a fourth-degree earthquake hazard zone [i.e. expected peak ground acceleration (PGA) is 0.1–0.2 g] according to the current official seismic hazard zonation map of Turkey, which was published in 1996. During the preparation of this map, Turkey was divided into 17 source regions. Using a probabilistic approach, the map was produced to show any 90% nonexceedance probability of PGA over a 50-year period.

In 1668, there were a series of earthquakes on 12, 15, and 17 August that caused structural damage and loss of life in Ankara (Ambraseys and Finkel, 1988, 1995). In the last 100 years, the following earthquakes occurred in or near Ankara, resulting in structural damage and loss of life: 19 April 1938, Kırşehir-Keskin ($M_S = 6.8$); 1 February

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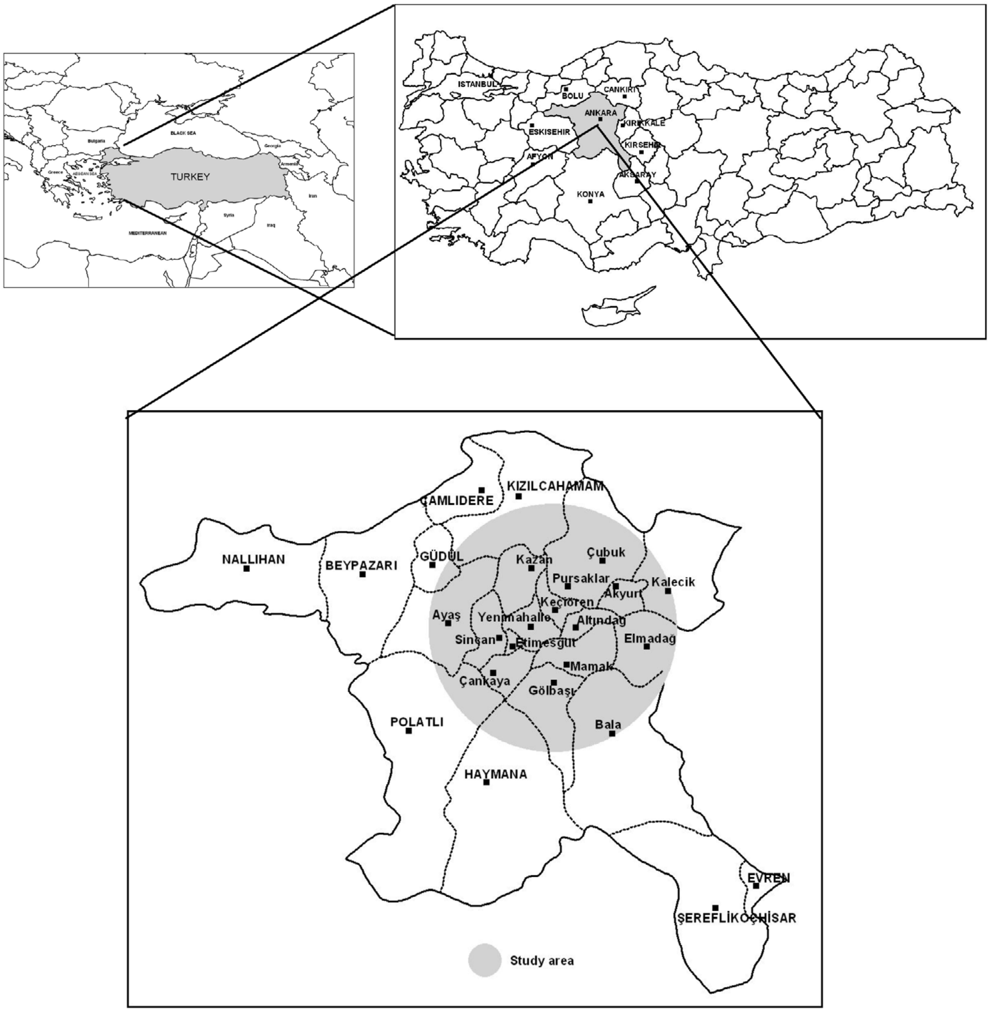

Figure 1. Location of the study area and the city of Ankara.

1944, Bolu-Gerede (M_W = 7.6); 21 April 1983, Köşker (M_S = 4.6); 6 June 2000, Orta-Çankırı (M_S = 6.0); 31 July 2005, Bala (M_W = 6.0); 20 December 2007, Bala (M_W = 5.7); and 27 December 2007, Bala (M_S = 6.0).

In general, Ankara is known to have low seismicity and safety from earthquakes. However, earthquakes in the recent past and recent studies show that this common belief might not be correct. More research on the seismic risk to Ankara has led to an increase in the number of scientists who think that Ankara faces a considerable degree of earthquake hazard. Various studies have been conducted on the earthquake hazard and seismicity of Ankara by Tabban (1976), Ergünay (1978), Çetinkaya et al. (1993), Kasapoğlu (2000, 2007), Pampal (2000, 2006, 2008), Koçyiğit (2000, 2008a, 2008b, 2009), Koçyiğit and Deveci (2008), Kaplan (2004), Koçyiğit and Kaplan (2004), Seyitoğlu et al. (2006), Dirik et al. (2008), Utku (2008), Kalafat et al. (2008), and Gökten and Varol (2010). However, none of these studies used a probabilistic approach to estimate earthquake hazard and none produced earthquake hazard maps for Ankara. This study aims to use the available information to prepare earthquake hazard maps of Ankara using probability methods.

Currently, no international work exists on the earthquake hazard and seismicity of Ankara, Turkey. However, a number of studies have been prepared for different parts of Turkey and internationally. Seismic hazard studies conducted in Turkey include that of Orhan et al. (2007) for Eskişehir Province, Güllü et al. (2008) for Gaziantep Province, Kalkan et al. (2009) for the Marmara Region, Deniz et al. (2010) for İzmir Province, and Selçuk et al. (2007) for Van Province.

2. Materials and methods

2.1. Tectonic characteristics of the research area

The study region is located between 38°N and 42°N and 30°E and 35°E. Four main fault lines surround the city: the NAF in the north, the Ezinepazarı Fault in the east, the Tuzgölü Fault Zone in the south-east, and the İnönü-Eskişehir Fault Zone in the west and south-west. These faults are included within the study region as any earthquake that affects Ankara in the future is mostly likely to result from a rupture in one of them.

Koçyiğit (2008a) defined a 'neotectonic regime' as a system that begins in any geological time or geological period and continues until the present. He defined a 'neotectonic period' as the period in which a neotectonic regime is effective. Moreover, he defined the region of these activities as a 'neotectonic region'. Figure 2 shows Koçyiğit and Özacar's (2003) categorisation of Turkey into 4 neotectonic regions according to the features of faults and characteristics of the earthquakes that these faults produce.

In Figure 2, Ankara's provincial borders are split into parts by the İnönü-Eskişehir Fault Zone. It is observed that the area, which is to the north, north-east, and east of this system, is a strike-slip neotectonic regime with normal components. In other words, it is a pressure-expansion type of neotectonic regime, whereas the area to the west, south-west, and south is an extensional neotectonic regime.

2.2. Methodology

In determination of the earthquake hazard for Ankara, we first determine the size of the study region by using the information on active faults in the region and the maximum magnitude of the earthquakes that these faults could produce. Using the earthquake catalogues and studies on active tectonics, previous earthquakes and active faults in the Ankara region are then defined. This information enables us to identify the source regions that cause earthquakes and to estimate seismic hazard parameters. It is also used to help us determine attenuation relations and to map the earthquake hazard of Ankara using EZ-FRISK 7.52.0.1 software.

Many studies have been undertaken for the purpose of generating earthquake hazard maps, which in turn inform the earthquake risk mitigation process. Probabilistic seismic hazard analysis (PSHA) was first introduced by Cornell (1968). Many researchers conduct studies following his ideas. Although there are new revisions of his work, the original work of Cornell (1968) is still considered as the basis.

'Stochastic' methods have also been developed to eliminate uncertainty in models used to determine the likely place, time, and magnitude of possible future earthquakes. Various stochastic models have been developed to better forecast earthquakes using historical information. Poisson models have become the preferred approach as they are simple to apply and provide more approximate results than more complex earthquake hazard determination models. Generally, Poisson models are sufficient and work well with earthquakes of medium to large magnitude (Kiremidjian et al., 1992). Moreover, Yücemen and Akkaya (1995) ran a comparison of Poisson, extreme value, and Markov models on earthquake hazards for the NAF and found the Poisson method to provide a

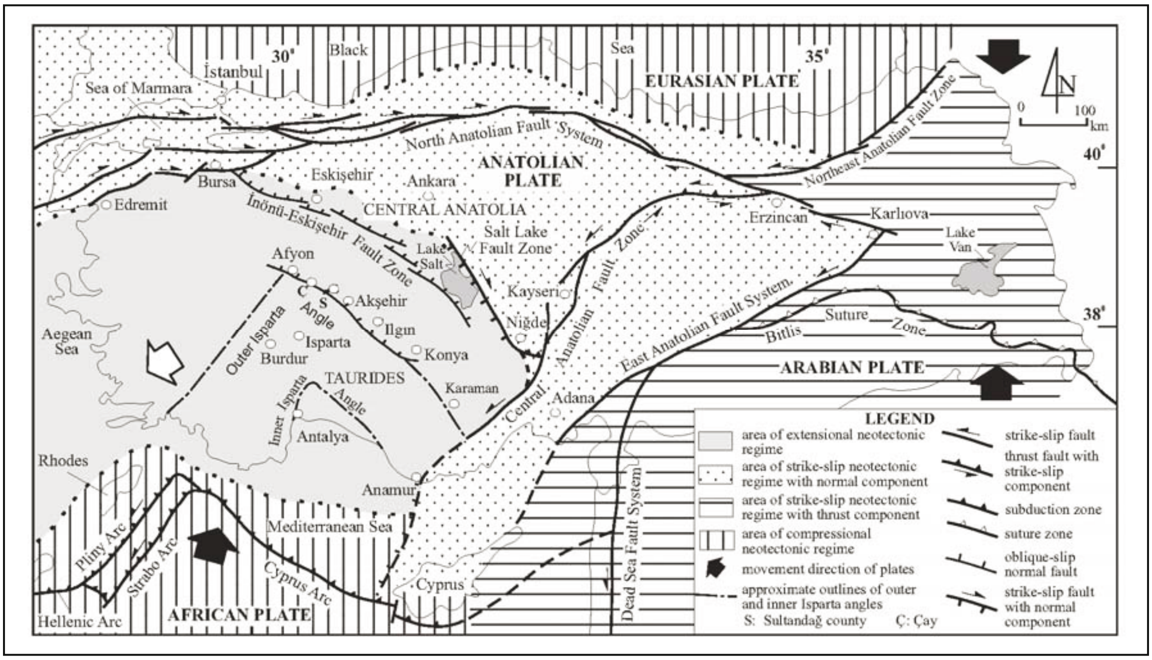

Figure 2. Active tectonic regions in Turkey (Koçyiğit and Özacar, 2003).

better fit. These findings give motivation for this study.

The most widely used model in probability calculations is the Poisson model, which assumes that earthquakes are without memory, meaning that all those that occur within an area do so independently from each other, both in terms of location and time.

The properties of the Poisson model were given by Kramer (1995):

1) The number of occurrences in a time interval is independent of any other time period,

2) The probability of the occurrence of an earthquake during a short time interval is proportional to the length of this time interval,

3) The probability of more than one earthquake occurrence in a short time interval is negligible.

According to the Poisson model, the probability of occurrence of x earthquakes at time t with magnitude M > M_0 in a study region is given by:

$$P_x(t) = \frac{e^{-\upsilon t}(\upsilon t)^x}{x!}$$

where $P_x(t)$ is the probability of occurrence of x earthquakes at time t, x is the number of events, and υ is the average number of earthquakes with magnitude M_0 or greater in unit time (generally 1 year).

The basic steps used during the analysis can be listed as follows:

1) Information on active faults in Ankara and its surroundings is collected.

2) Using this information, the size of the study region is decided.

3) Eleven earthquake catalogues of Turkey are investigated to prepare the most accurate and complete earthquake catalogue for the study region.

4) The findings of all studies on active faults in Ankara and its surroundings are included in the mapping of the study region.

5) Locations where earthquakes may occur are determined according to the mapping of active faults and previous earthquakes.

6) Magnitude–frequency relations are used to determine the earthquake parameters for the study region.

7) As no attenuation relation study exists for Ankara and its surroundings, data from 10 general studies of Turkey are compared and the attenuation relation produced by the study closest to the average values is determined.

8) Computational work for earthquake hazard analysis is conducted.

9) The results of the analysis are combined with Geographic Information System (GIS) values to facilitate the preparation of an earthquake hazard map for the study region.

2.3. The earthquake database

The history of earthquakes in the research area has been assembled from 11 earthquake catalogues available in Turkey, namely those of Ergin et al. (1967, 1971), Öcal (1968a, 1968b), Alsan et al. (1975), Pınar and Lahn (1952), Gencoğlu et al. (1990), Kalafat et al. (2011), the Earthquake Department of the Turkish Disaster and Emergency Management Presidency, the Boğaziçi University Kandilli Observatory and Earthquake Research Institute, and the Gazi University Earthquake Engineering Implementation and Research Centre. The researchers aimed to compile a comprehensive and accurate catalogue from detailed comparison of data relating to the period between 1900 and 2010.

The conversion of earthquake data expressed in different magnitude scales to moment magnitude (Mw) is done by using Mw = 0.6798Ms + 2.0402; Mw = 1.2413Mb – 0.8994; Mw = 0.9495Md + 0.4181; Mw = 0.7768M_L + 1.5921, as suggested by Ulusay et al. (2004), where Mw is moment magnitude, Ms is surface magnitude, Mb is body wave magnitude, Md is duration magnitude, and M_L is local magnitude.

It is necessary to separate preshock and aftershock events from the data to validate the independency assumption of the Poisson model. For this reason, pre- and aftershocks have been excluded from this study using the method suggested by Deniz (2006).

2.4. Delineation of the seismic source areas

The research area is defined as 38°N to 42°N and 30°E to 35°E with the effect of the NAF to the north, the İnönü-Eskişehir and Akşehir Fault Zones to the west, Tuzgölü Fault to the south-east, and Ezinepazarı Fault to the east (Figure 3). The active faults in this area were studied by Şaroğlu et al. (1987, 1992), Pampal and Kozlu (2000), Seyitoğlu (2007), Koçyiğit (1991, 2000, 2008a, 2008b, 2009), Koçyiğit and Deveci (2008), Dirik and Göncüoğlu (1996), Dirik et al. (1998), Çemen et al. (1999), Eren (2000), Dirik (2001), Bozkurt (2001), Koçyiğit et al. (2001), Özsayın and Dirik (2007), and Gökten and Varol (2010). A new active fault map of Ankara is prepared by using existing research results and by combining available information to close any gaps in previous studies (see Figure 3). Nineteen seismic source areas are defined within the research area. These source areas have been determined according to the findings of studies by Erdik et al. (1985), Gülkan et al. (1993), TEFER (2001), and DLH (2007), which were conducted on the basis of a Turkish scale with historical earthquakes including earthquake data from between 1900 and 2010 with magnitude greater than 3 (M ≥ 3), and from consulting active fault maps prepared by various scientists. It is assumed that the probability of earthquake occurrence is the same in all parts of a source area. The areas thus identified are the NAF, Akşehir Fault System,

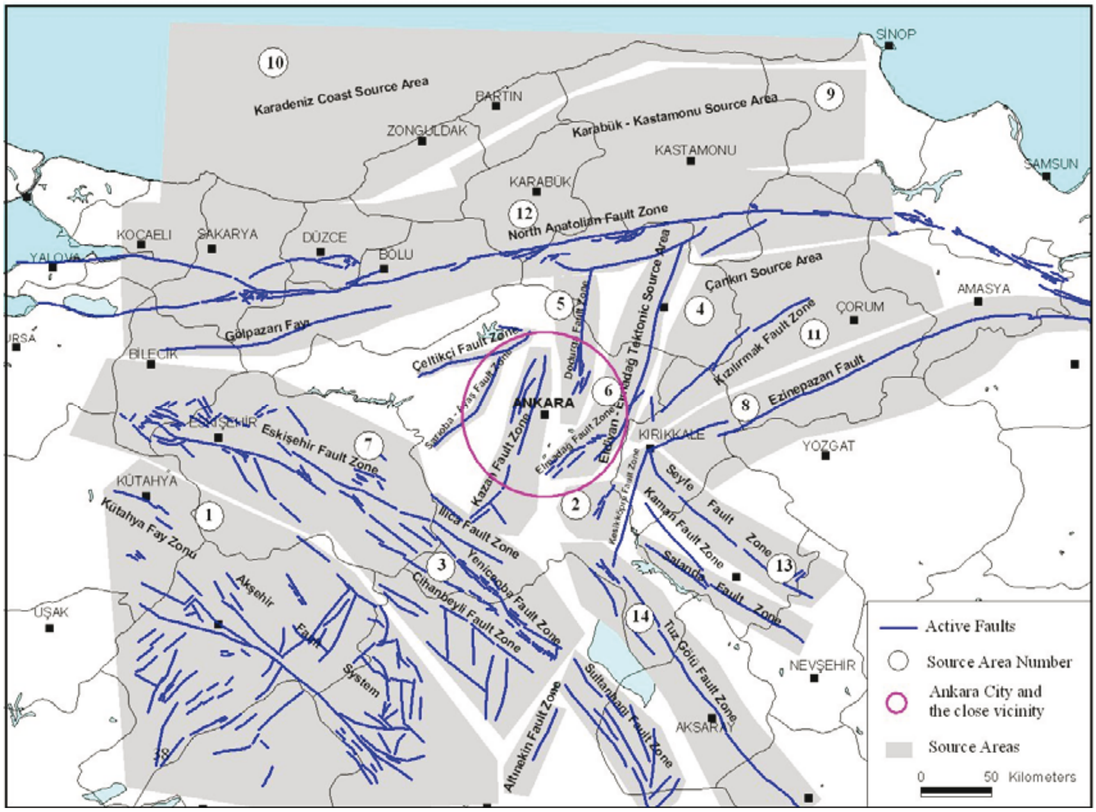

Figure 3. Source areas for the Ankara city and the close vicinity.

Eskişehir Fault Zone, Ezinepazarı Fault, Tuzgölü Fault Zone, Seyfe Fault Zone, Cihanbeyli-Yeniceoba Fault Zone, Dodurga Fault Zone, Elmadağ-Eldivan Tectonic Junction, İnönü-Eskişehir Fault Zone, and Kızılırmak Fault Zone (see Figure 3).

2.5. Determination of seismic hazard parameters

The following equation by Gutenberg and Richter is used to determine seismicity and probability distribution of earthquake magnitude in relation to the total number of earthquakes in a given year (Gutenberg and Richter, 1944):

$$\log N = a - bM,$$

where N is the number of earthquakes with magnitude of M or above in a given year, a and b are regression coefficients, and M is the magnitude of the earthquake. The coefficients here take different values depending on the specific tectonic features of the earthquake source zone. Coefficient a is the 'annual seismic activity index', which depends on the size of the source region, observation period, and earthquake activity in that period. Coefficient b is the 'seismotectonic parameter', which varies with respect to the tectonic characteristics of the source region (Gutenberg and Richter, 1944; Tabban and Gencoğlu, 1975). Studies show that increasing values of b are a sign of the accumulation of energy, whereas declining values denote energy release.

The standard Gutenberg–Richter recurrence law can also be expressed as follows (Yücemen, 1982):

$$N_M = 10^{a - bM} = \exp^{(\alpha - \beta M)},$$

where $\alpha = 2.303a$, $\beta = 2.303b$, and M is magnitude. The standard Gutenberg–Richter law includes all earthquakes between $-\infty$ and $+\infty$. However, small earthquakes are not used in the calculations since they do not cause losses in construction and the figures are not always reliable. Historical earthquake data proved that the release of infinite energy is impossible; that is, there is an upper limit for earthquakes, and this upper limit takes different values in each region and each source. In earthquake hazard analysis, generally, the lower limit is Mmin = 4.0 or 4.5. The maximum earthquake magnitude is determined by using one or more of the following: historical earthquake data, palaeoseismological studies, length of faults, segmentation technique, magnitude–frequency relations, maximum probability statistics, correlation between rupture length and magnitude and strike-slip–magnitude.

If magnitude is known and can be predicted, then the annual average exceedance rate (λ_M), cumulative distribution function ($F_M(M)$), and probability density function ($f_M(M)$) are as follows (McGuire and Arabasz, 1990):

$$\lambda_M = \nu \frac{\exp[-\beta(M - M_0)] - \exp[-\beta(M_{\max} - M_0)]}{1 - \exp[-\beta(M_{\max} - M_0)]}$$

$M_0 \leq M \leq M_{\max}$,

$$F_M(M) = P[M < M | M_0 \leq M \leq M_{\max}] = \frac{1 - \exp[-\beta(M - M_0)]}{1 - \exp[-\beta(M_{\max} - M_0)]}$$

$$f_M(M) = \frac{\beta \exp[-\beta(M - M_0)]}{1 - \exp[-\beta(M_{\max} - M_0)]}$$

where M_0 is the minimum earthquake and Mmax is the maximum earthquake with the smallest and the largest magnitudes, respectively.

The Sultanhanı, Altıntekin, Salanda, Sarıoba-Ayaş, and Kazan Fault Zone source areas (for details of all 19 source regions, see Figure 3) are not included in the computations since the number of earthquakes in these areas is not sufficient to produce significant results in the analysis. The İnönü-Eskişehir Fault System comprises the Eskişehir, Ilıca, Yeniceoba, Cihanbeyli, and Sultanhanı Fault Zones. The Sultanhanı Fault Zone is not included in the hazard analysis since only 1 earthquake occurred there ($M \geq 4.0$) between 1900 and 2010. The İnönü-Eskişehir Fault Zone is divided into 2 source areas since the Eskişehir Fault Zone is a right-literal strike-slip and the Cihanbeyli and Yeniceoba fault zones are normal faults.

The maximum earthquake magnitude is obtained by using graphs of different magnitude–frequency relations for each source area and the least square (LS) method. The intersection point where the curve obtained by LS meets the x-axis is used as the maximum magnitude (M_{max1}) value to occur in that source area. This value is shown in the Table in the M_{max1} column. The selected seismic source areas in Ankara and the corresponding seismic parameter estimates obtained from the literature available are provided in the Table.

The maximum earthquake magnitude given by M_{max2} in the Table is obtained by using the following relation as suggested by Deniz (2006):

$M_{max2} = ((M_{gm} + 0.5) + (M_{uzm})) / 2$,

where M_{max2} is the maximum earthquake magnitude, M_{gm} is the maximum earthquake magnitude observed at the resource area, and M_{uzm} is the maximum earthquake magnitude defined by the observation of an expert.

The activity ratios are calculated by dividing the number of earthquakes with $M \geq 4$ that occurred in each source during the 1900–2010 observation period. The value of β is obtained by multiplying the value of b by 2.303.

2.6. Selection of attenuation relation

Attenuation relations are used to find how PGA values decrease over distance. Acceleration values vary from the main rock until they reach the surface depending on the structure of the ground. In this study, the attenuation of the acceleration at the main rock is used. Attenuation relations were developed for Turkey by İnan et al. (1996), Aydan (2001), Gülkan and Kalkan (2002), Kalkan and Gülkan (2004),Ulusay et al. (2004), Beyaz et al. (2004), Yunatcı (2010), Akkar and Çağnan (2010), Kayabalı and Beyaz (2011), and Akkar et al. (2014). In Figure 4, ground acceleration values for Mw = 7.4 and various distances are provided, which are computed by using the previously

Table. Seismic source areas in Ankara and corresponding parameters.

No.	Seismic source name	a	b	M_{min}	M_{max1}	M_{max2}	β	Activity ratio
1	Akşehir Fault System	6.257	0.858	4.0	7.3	7.5	1.976	2.109
2	Bala	5.381	0.871	4.0	6.2	6.2	2.004	0.146
3	Cihanbeyli-Yeniceoba Fault Zone	7.799	1.342	4.0	6.2	6.5	3.091	0.200
4	Çankırı	4.504	0.699	4.0	6.5	6.5	1.610	0.136
5	Dodurga Fault Zone	5.192	0.843	4.0	6.2	6.2	1.942	0.182
6	Eldivan-Elmadağ Tectonic Junction	6.473	1.079	4.0	6.0	6.5	2.485	0.218
7	İnönü-Eskişehir Fault Zone	7.289	1.163	4.0	6.5	7.0	2.677	0.455
8	Ezinepazarı Fault	6.061	0.942	4.0	6.4	7.0	2.169	0.318
9	Karabük-Kastamonu	5.270	0.843	4.0	6.3	6.3	1.941	0.155
10	Karadeniz Coast	5.014	0.751	4.0	6.7	6.8	1.730	0.427
11	Kızılırmak Fault Zone	5.868	0.954	4.0	6.2	6.5	2.196	0.200
12	North Anatolia Fault Zone	6.020	0.776	4.0	7.8	8.0	1.788	1.973
13	Seyfe Fault Zone	2.645	0.398	4.0	6.7	7.0	0.9174	0.0636
14	Tuzgölü Fault Zone	4.900	0.813	4.0	7.0	7.3	1.8718	0.1182

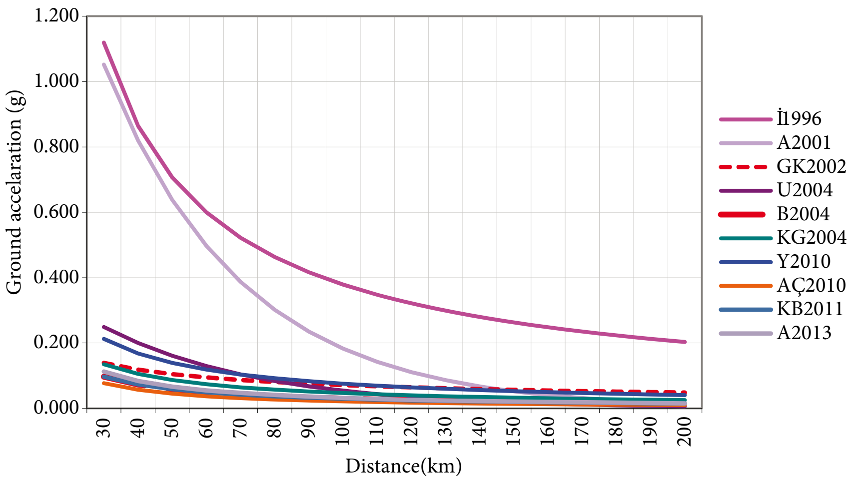

Figure 4. The change in ground acceleration versus distance with respect to different attenuation relations.

given attenuation relations. The minimum values are obtained from the attenuation relation of Akkar and Çağnan (2010) and the maximum values are obtained from that of İnan et al. (1996). In this study, the attenuation relation developed by Gülkan and Kalkan (2002), which gives average values of 10 relations suggested for Turkey in the references above, is used.

Gülkan and Kalkan (2002) obtained this attenuation relation by using 93 ground movement records, obtained from 47 horizontal components caused by 18 earthquakes with Mw ≥ 5.0, which occurred in Turkey between 1976 and 1999.

$\ln PHA = b_1 + b_2 (Mw - 6) + b_3 (Mw - 6)^2 + b_5 \ln(r) + b_v \ln(Vs/Va)$

Next, the formula of maximum ground acceleration is provided, where the parameter estimates from the attenuation relation are substituted (it is suggested that the related references be consulted for various period parameter values with a 5% damping ratio):

$LnPHA = -0.682 + 0.253 (Mw - 6) + 0.036 (Mw - 6)^2 - 0.562 \ln(r) - 0.297 \ln(Vs/Va)$,

$r = (R^2 + h^2)^{1/2}$,

where PHA is maximum horizontal acceleration (g), R is the closest distance to surface rupture (km), Mw is moment magnitude, h is assumed depth (km) (=4.48), Va = 1381, Vs is velocity of shear wave (700 m/s), and σ = 0.562 (standard deviation).

3. Results

Sufficient information was available in 14 of the main source regions, as listed in the Table. These source regions were selected using active tectonic studies, earthquakes causing damage before and after 1900, information about earthquakes of magnitude >3, and data from earthquake hazard studies using the Turkish scale.

A comprehensive and accurate earthquake catalogue for Ankara was compiled from 11 different earthquake catalogues of Turkey. Earthquakes recorded in different scales were converted to moment magnitude (Mw). Accordingly, there were 742 earthquakes of magnitude 4.0 ≤ Mw < 5.0, 330 earthquakes of magnitude 5.0 ≤ Mw < 6.0, 29 earthquakes of magnitude 6.0 ≤ Mw < 7.0, and 3 earthquakes of magnitude 7.0 ≤ Mw < 8.0.

An earthquake hazard analysis of the study region could then be conducted using the values in the Table and EZ-FRISK 7.52.0.1 software. The computations were initially based on the attenuation relation suggested by Gülkan and Kalkan (2002) and M_{max1} values, then using the values of M_{max2}, where the peak ground acceleration values of exact related points were calculated by using the average of these values. The area under investigation was segmented into a grid showing 0.1° increments. The same operations were conducted for each knot point (100 points) and the possible acceleration values obtained. An earthquake hazard map was then generated by combining knots of equal values.

It is observed that within the city of Ankara and its environs, ground acceleration values in main rock change between 0.15 g and 0.25 g with an exceedance probability of 40% in a 50-year return period, ground acceleration values in main rock change between 0.15 g and 0.35 g with an exceedance probability of 20% in a 50-year return period, ground acceleration values in main rock change between 0.20 g and 0.40 g with an exceedance probability of 10% in a 50-year return period, and ground acceleration values in main rock change between 0.20 g and 0.45 g with an exceedance probability of 5% in a 50-year return period. These findings enabled the preparation of earthquake hazard maps for Ankara as presented in Figures 5–8.

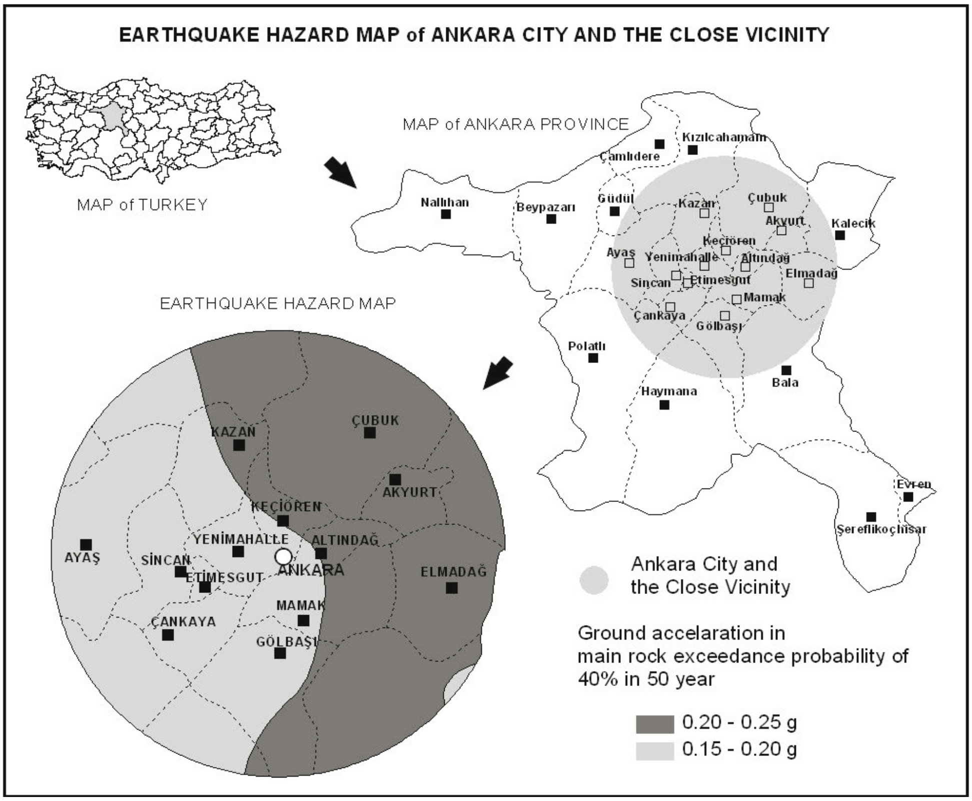

Figure 5. Ground acceleration in main rock with exceedance probability of 40% in 50-year period.

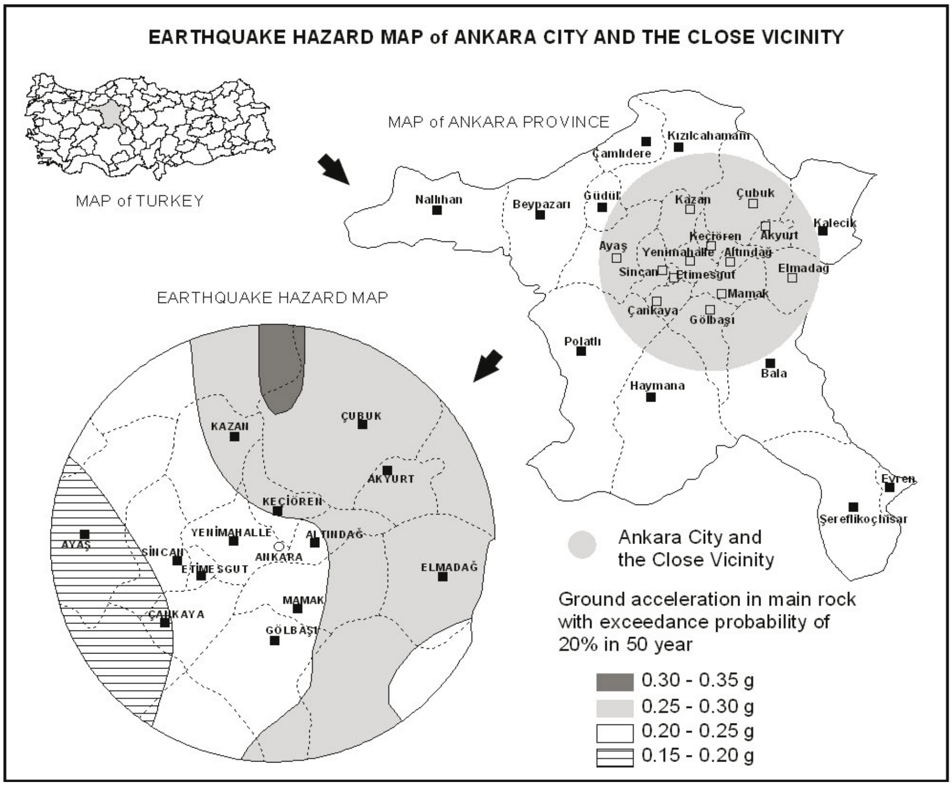

Figure 6. Ground acceleration in main rock with an exceedance probability of 20% in a 50-year period.

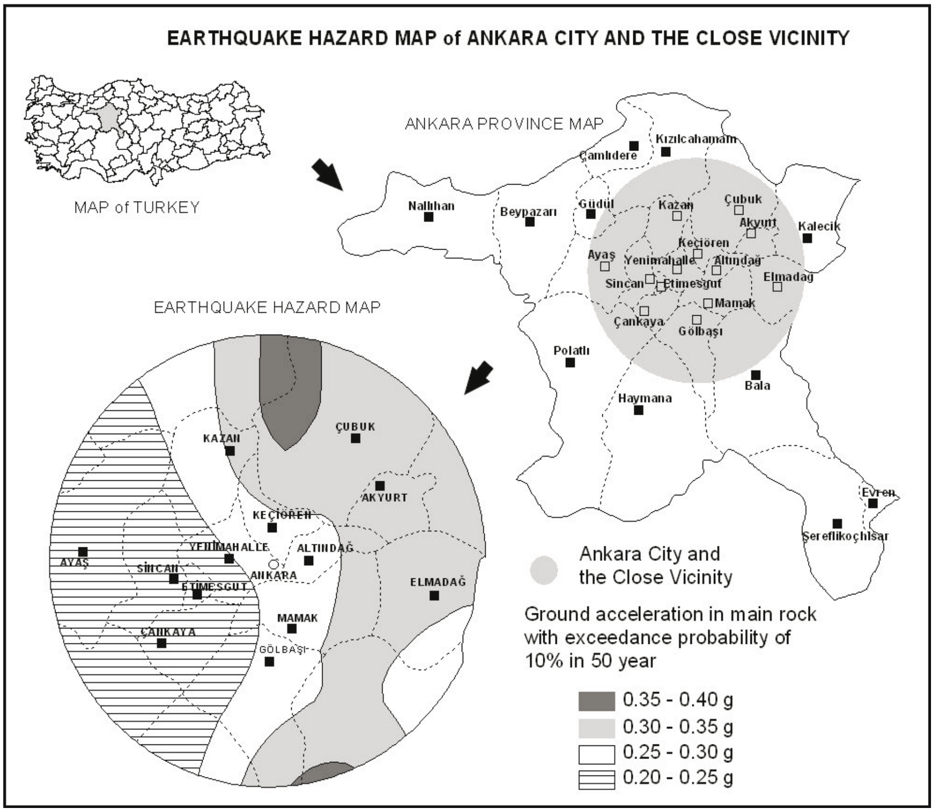

Figure 7. Ground acceleration in main rock with an exceedance probability of 10% in a 50-year period.

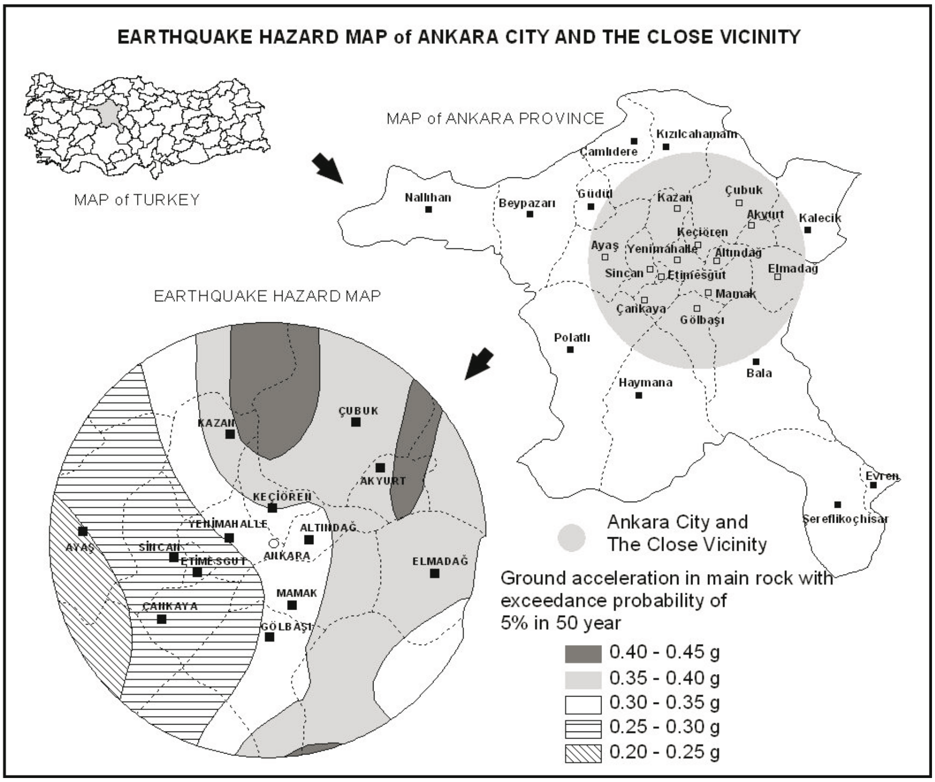

Figure 8. Ground acceleration in main rock with an exceedance probability of 5% in a 50-year period.

The results of the earthquake hazard analysis represent the joint effect of seismic sources, the magnitude of the earthquakes depending on these sources, and the distance between the source area and the study region. These results enabled us to conduct a deaggregation of seismic hazard analysis of the Ankara city centre (40.00°N, 32.80°E) to determine which source area and distance make the most significant contribution to the ground acceleration values (Figures 9 and 10). These figures indicate that the NAF, the Akşehir fault lines, and distances of 100–130 km mainly contribute to the results.

The earthquake hazard risk of a region is calculated by using probabilistic and deterministic methods. In the deterministic method, earthquake hazard is computed only by using maximum earthquake magnitude and distance information. A mathematical formula is used, which involves no uncertainty. This method involves neither probabilistic methods nor the reoccurrence period of the earthquakes.

In deterministic earthquake hazard analysis, first, the active fault lines and possible source regions that can produce earthquakes and their corresponding maximum probable earthquake magnitudes are determined. The distance between source regions and the research area is then calculated. Lastly, under the assumption that an earthquake would occur there and by using a suitable attenuation relation, ground movement parameters such as intensity and acceleration are estimated.

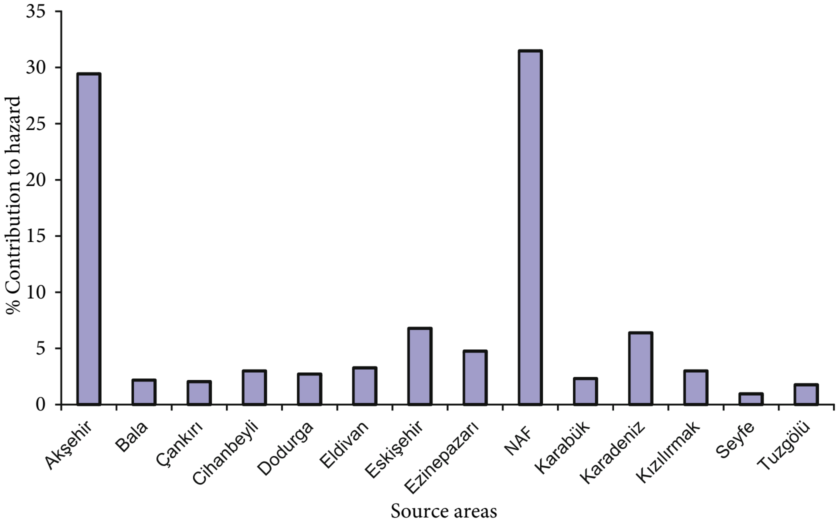

Figure 9. The plot of the results of the deaggregation in terms of source areas.

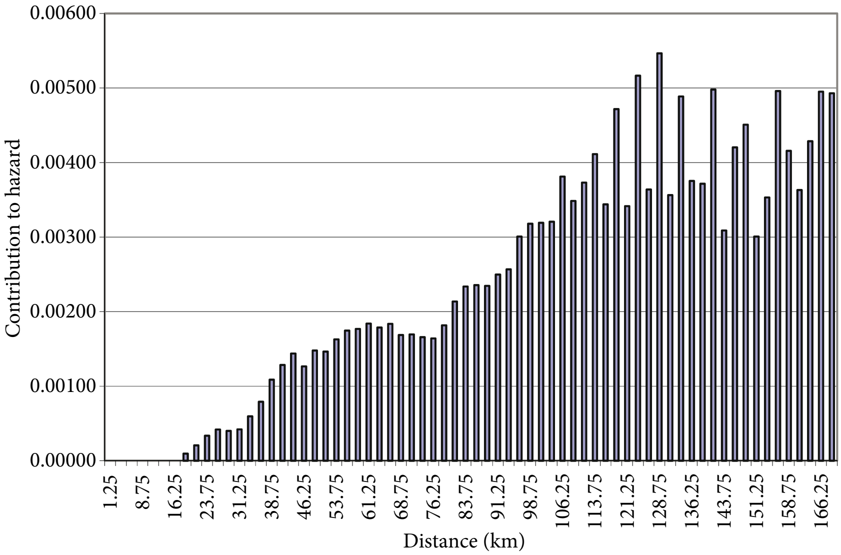

Figure 10. The plot of the results of the deaggregation in terms of distance.

In this study, the maximum ground acceleration at the point determined by deaggregation analysis is also defined by using a deterministic method to be able to observe the difference between the results of using probabilistic and deterministic methods.

At first, the distance of all source regions, which are given in Table 1, to the place of deaggregation analysis is calculated. Next, the attenuation relation as suggested by Gülkan and Kalkan (2002) is used to obtain maximum ground acceleration values at that point for all source regions. The maximum number among these values calculated is accepted as the PGA at the point of the analysis. The maximum acceleration value is obtained for a possible earthquake of magnitude 6.2 at the closest distance of the Dodurga Fault Line (5 km) to the deaggregation analysis point (5 km). The procedure above and the use of the deterministic method result in a PGA value of 0.224 g in the source region.

However, when the probabilistic method is applied, a higher figure of 0.250 g is seen for the same point with an exceedance probability of 90% in a 50-year return period. With the probabilistic method, ground movement is calculated according to the place of the earthquake, time, magnitude, and uncertainty of ground movement parameters.

This finding is in accordance with those of Güner and Yıldız (2011), who suggested that the probabilistic method may produce higher values for ground movement parameters than those rendered using a deterministic approach. They also mentioned that PGA values obtained by the deterministic method can be used as an upper bound in such studies.

4. Discussion

The official Earthquake Hazard Zone Map of the Ministry of Public Works and Settlement of Turkey (1996) was prepared according to ground acceleration values with an exceedance probability of 10% in a 50-year return period. According to this map, the Ankara city centre is situated in a fourth-degree (0.10–0.20 g) earthquake hazard zone. The building regulations in Ankara have therefore been applied according to this information. In this study, PGA values with an exceedance probability of 10% in a 50-year return period are estimated to range from 0.2 g to 0.4 g for Ankara. This result shows the need for detailed revision of the earthquake hazard of the city of Ankara in the current official Earthquake Hazard Zone Map of Turkey.

The earthquake hazard maps suggested for the city of Ankara in this paper can be used as supporting documents in the preparation of plans for construction, development, emergency management, disaster mitigation, and management of the environment. Furthermore, in this study, the calculated maximum ground acceleration is equal to the ground acceleration value in the main rock. These results can therefore be reliably used in provincial development plans, which should refer to geological and geotechnical studies and ground surveys. In this way, scientific studies should enlighten policy decisions. This is a great need in a country like Turkey, which suffers heavily every time an earthquake strikes. Many buildings collapse in Turkey as a result of earthquakes, exacerbated by a lack of ground surveys, geotechnical studies, and enforcement of building codes. If buildings are sufficiently strong, the risk of socioeconomic, cultural, and environmental losses will be significantly reduced. This paper aims to help reduce any possible future earthquake losses by providing earthquake hazard maps for Ankara to be used properly by the authorities.

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