CO_2TRACCS INTERNATIONAL WORKSHOP
Bucharest, 2 September, 2012

AN OVERVIEW AND GUIDELINES FOR PROBABILISTIC SEISMIC HAZARD MAPPING

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INTRODUCTION

In recent years more attention has been paid to the assessment of seismic hazard nucleating from active faults. The fact that more reliable values have been obtained for the fault parameters had a significant effect on this.

The seismic hazard assessment procedures taking into consideration the hazard nucleating from the faults and utilizing more appropriate stochastic models have become the current trend in seismic hazard mapping.

Accordingly, in the development of seismic hazard maps, one of the main concerns should be the assessment of the parameters of active faults.

BASIC STEPS

- Identification of the region selected as the affected area and compilation of a seismic database.

- The raw data in the earthquake catalogs have to be processed considering the following:
    - Magnitudes reported in different scales have to be converted to a common scale, preferably to the moment magnitude (M_w) scale. (HOMOGENIZATION)
    - Earthquake clusters should be identified and dependent events (fore and after shocks) be eliminated by defining space and time windows. (DECLUSTERING)
    - An analysis of catalog completeness has to be performed to obtain complete rates (i.e. complete number of events over a particular time period).

- Subdivision of the region to be studied into discrete seismic sources in the form of lines and areas.

- Preparation of a fault map, identification of the active ones and assessment of the parameters of active faults.

- The basic information required for an active fault is as follows:

  actual location, activity rate, type, orientation (direction, dip amount and direction), length, segments, age, total horizontal and vertical slip amount, annual slip rate, the magnitude and return period of the maximum likely (characteristic) earthquake, the date of the last characteristic earthquake.

- Plotting of a seismotectonic map that shows distribution of earthquake epicenters and their relationships with active faults.

- Distribution of past earthquake data to the different seismic sources consistent with their epicentral locations and assessment of the seismicity parameters for each seismic source.

- Identification of the areal background seismic sources to include the contribution of the earthquakes that could not be associated with any one of the faults. For this purpose spatially smoothed seismicity model (Frankel, 1995) and background areal seismic source with uniform seismicity can be used.

- Selection of the appropriate probabilistic and stochastic models for the description of the earthquake magnitude distribution and the earthquake occurrences in the time domain.

- In the classical Probabilistic Seismic Hazard Analysis (PSHA), earthquake occurrences are assumed to exhibit a Poisson process and magnitudes to be distributed exponentially.

- As an alternative to the Poisson process the renewal process, and as an alternative to the exponential magnitude distribution the characteristic earthquake (Schwartz and Coppersmith, 1984) or maximum magnitude models should be considered

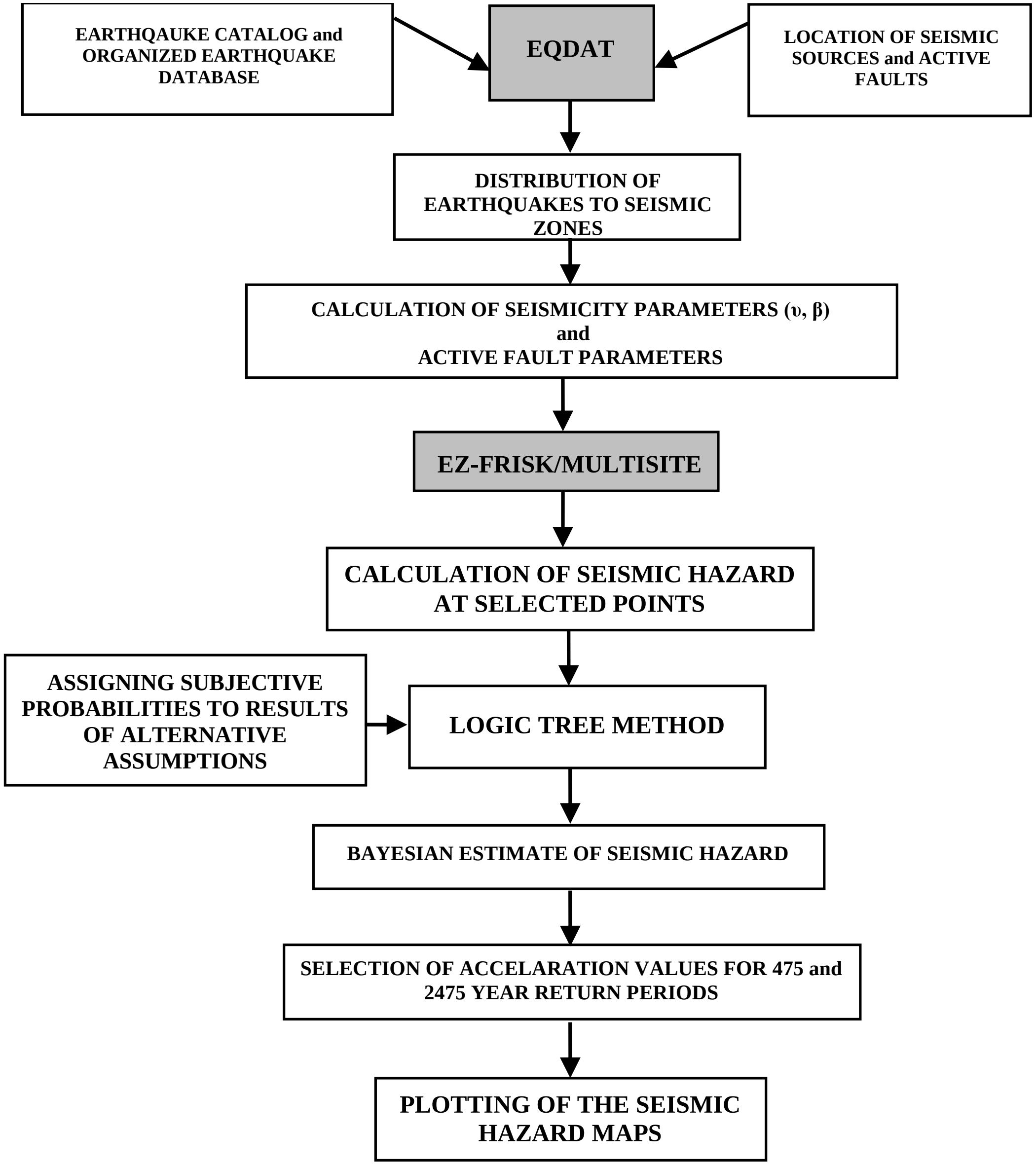
- Development or selection of a ground motion prediction (attenuation) equation.

- Preparation of a computational algorithm which will aggregate the seismic threat nucleating from different sources, yielding the probability distribution for the specified earthquake severity or ground-motion parameter at a specified location or at a number of locations if the aim is a seismic hazard map.

- Seismic hazard computations have to be carried out by making use of computers. Generally a series of computer programs are utilized to perform the necessary computations and plot the seismic hazard maps.

- Consideration of different sources of uncertainties (aleatory and epistemic) and reflection of their effects to the hazard results either directly or by conducting sensitivity studies and employing logic tree or similar statistical methods.

- Plotting of the seismic hazard maps corresponding to specified return periods.



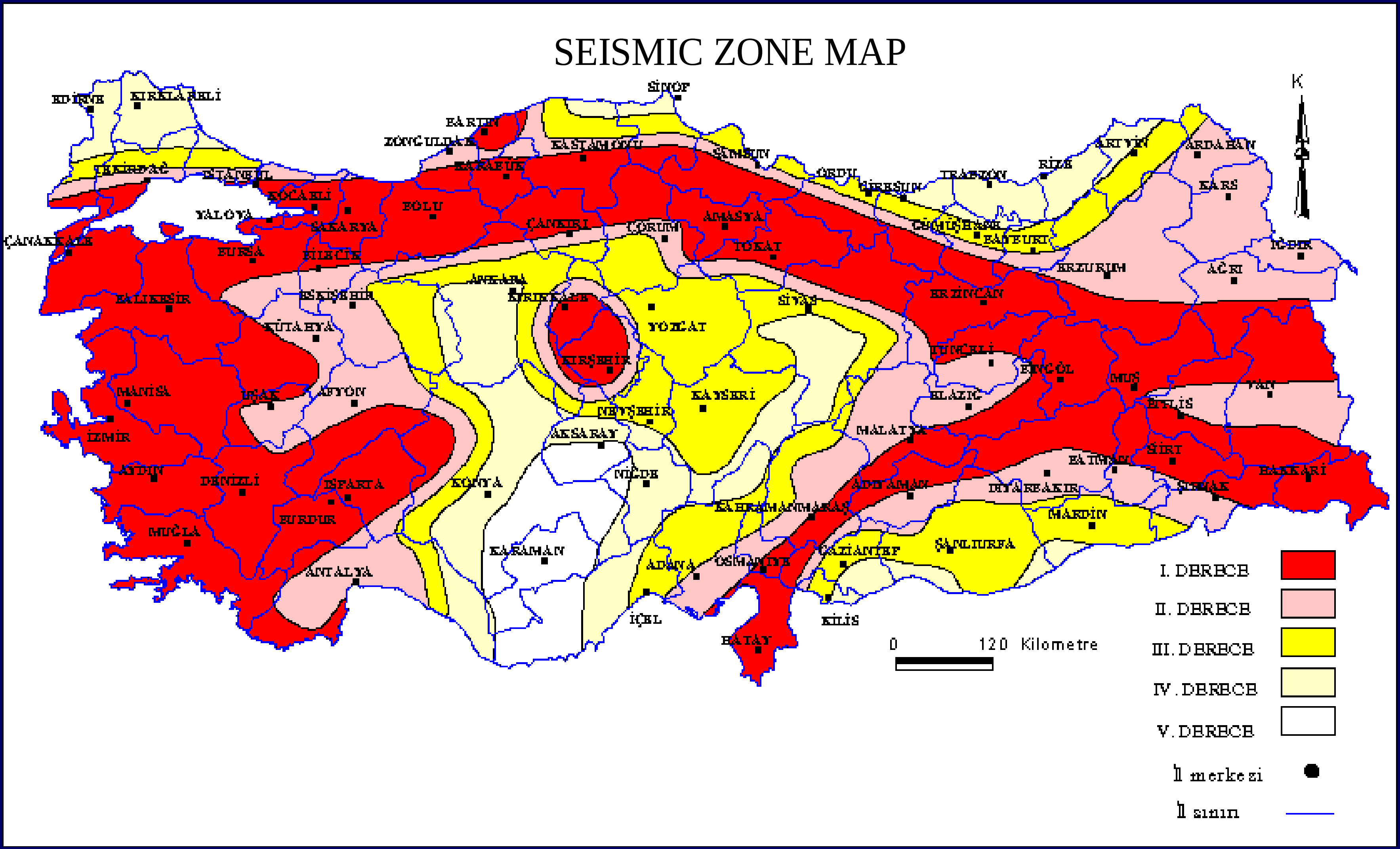
Flowchart showing the tasks and software needed for seismic hazard mapping

A CASE STUDY:
ASSESSMENT OF SEISMIC HAZARD FOR THE BURSA PROVINCE

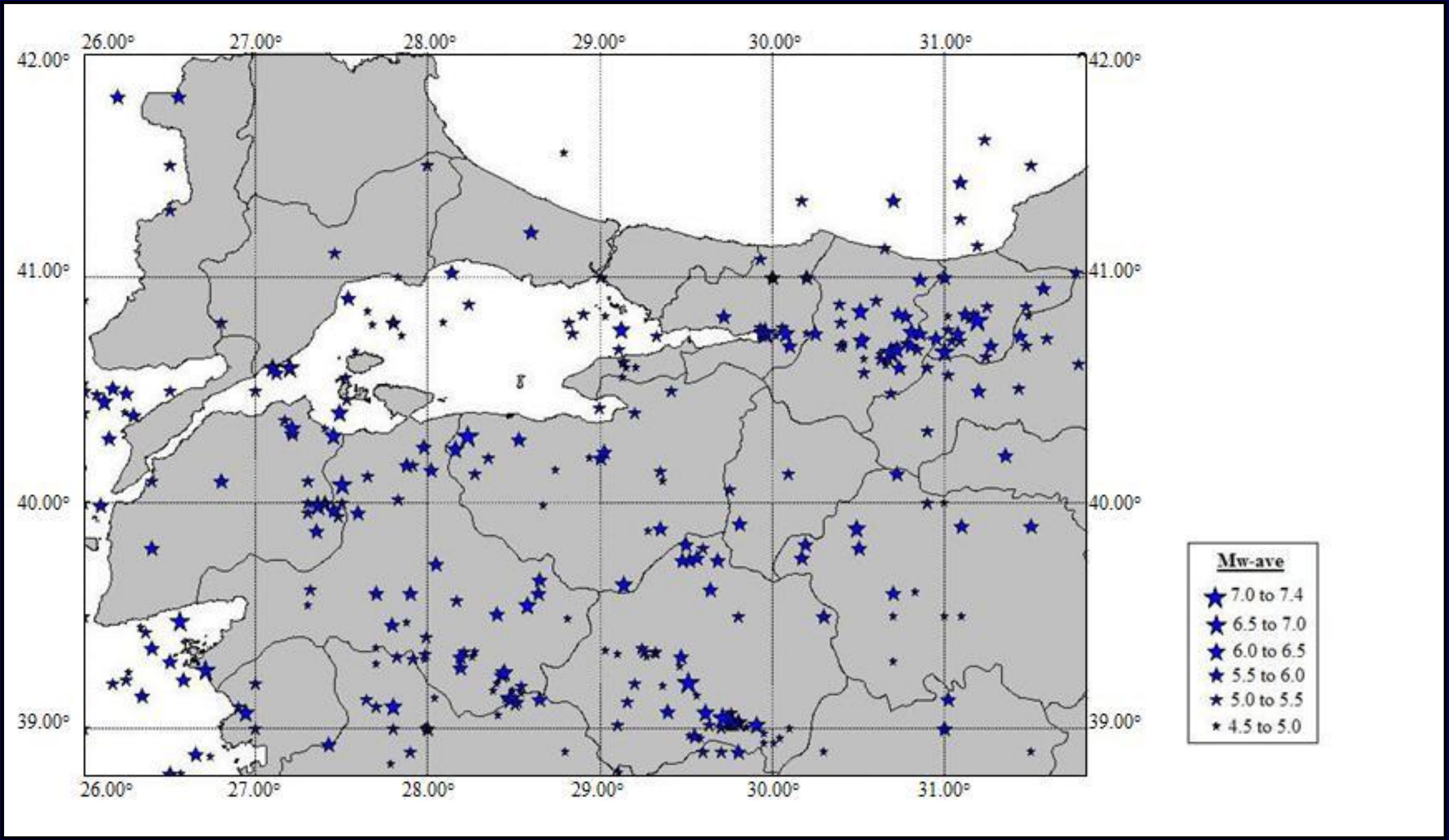
Seismic Database

- An earthquake catalog including earthquakes that occurred in the rectangular region bounded by 26.0°- 31.8° E longitudes and 38.8°- 42.0° N latitudes between years 1901 and 2006 is compiled. The magnitudes of earthquakes in this catalog are converted to the moment magnitude scale (M_w). Secondary events are removed from the original database to achieve independence among the earthquakes. Adjustment for incompleteness is made.

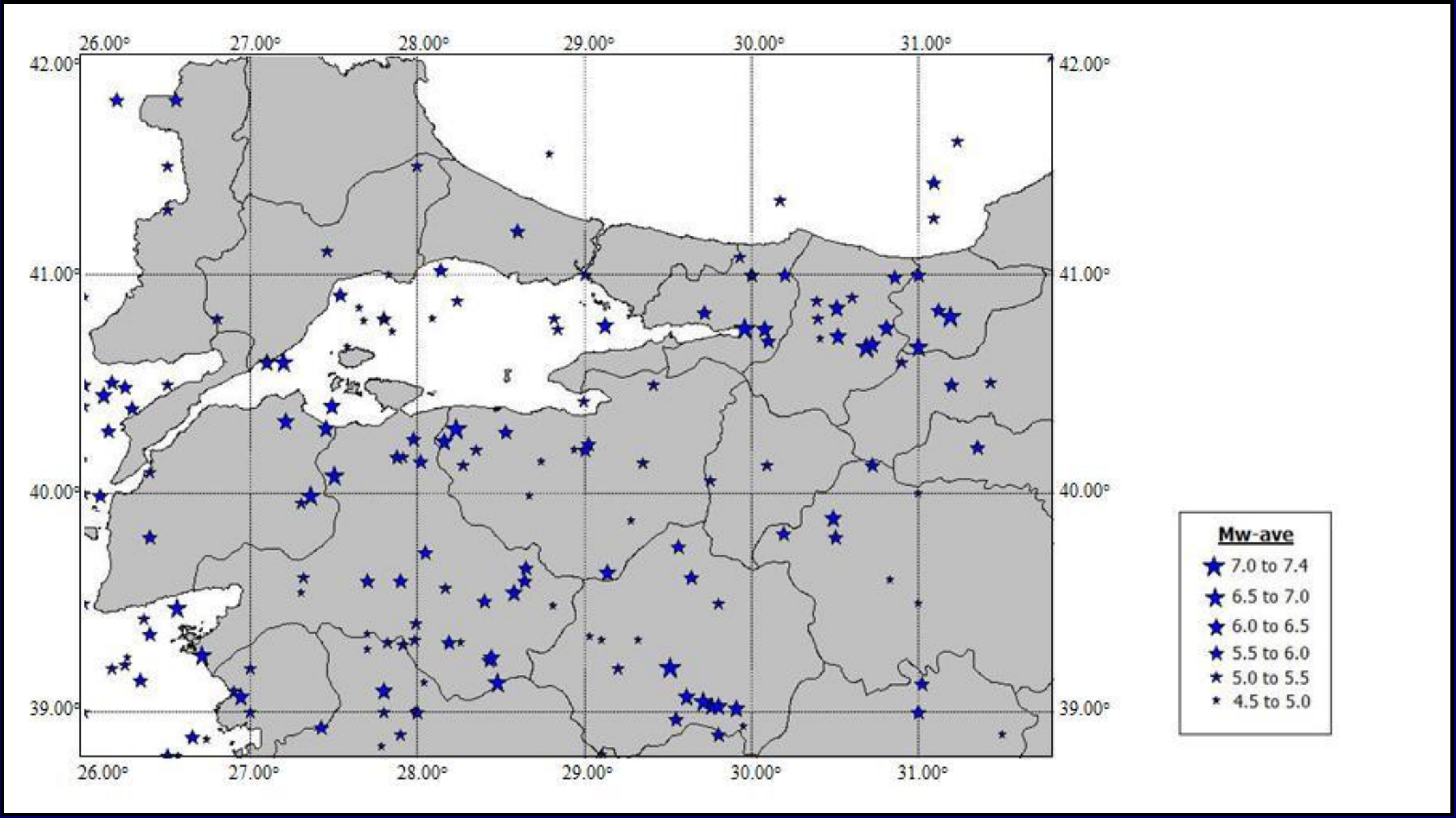
Seismic zone map of 1997 for Turkey



Map Showing the Spatial Distribution of All Earthquakes



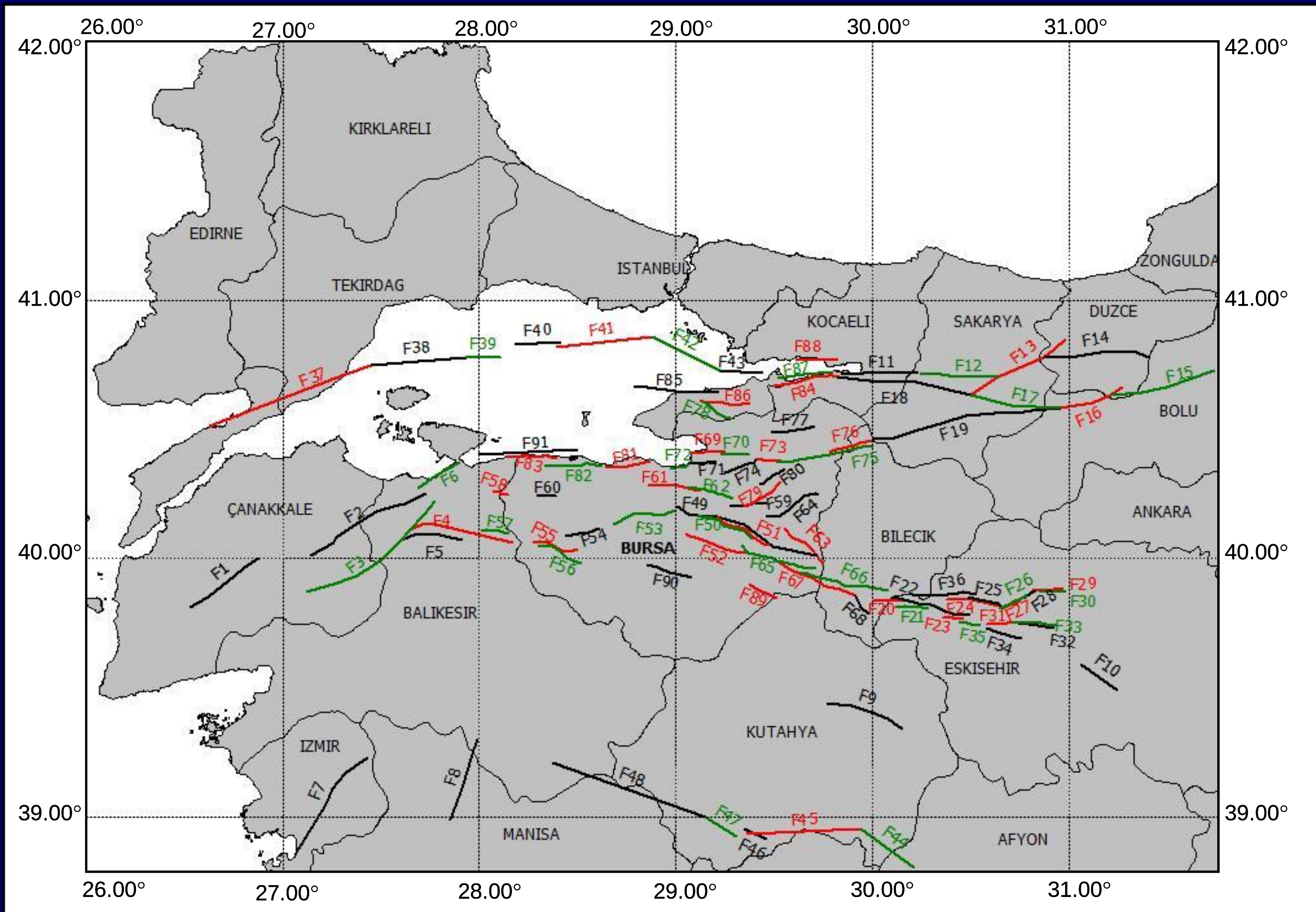
Map Showing the Spatial Distribution of Main Shocks



Seismic Sources

- Bursa Province is under the seismic threat caused by several normal and strike slip faults and fault segments in and around Bursa. In addition to the faults in the Bursa Province, this city can be affected by the seismic activity that may be created by the North Anatolian Fault System (NAFS) which is passing though north of Bursa. Accordingly, in addition to the faults in and near vicinity of the Bursa Province, main fault zones where any seismic activity may affect the city are taken into consideration.

Map Showing the Locations of Fault Segments Considered in the Assessment of Seismic Hazard for the Bursa Province



Methodology

The seismic hazard in the region is assessed by combining the contributions of:

i. earthquakes with magnitudes, M, between 4.5 and 6.0 that are not assigned to any fault or fault segment and termed as "background seismic activity",

ii. earthquakes with magnitudes equal or greater than 6.0 that may emanate from faults or fault segments by rupturing the whole or a large portion of their lengths and release the energy accumulated on them.

- Peak ground acceleration (PGA) is selected as the basic parameter for the seismic hazard evaluation.

- The attenuation relationships proposed by Boore et al. (1997) and Kalkan and Gulkan (2004) are used by assigning equal weights to estimate seismic hazard in terms of PGA.

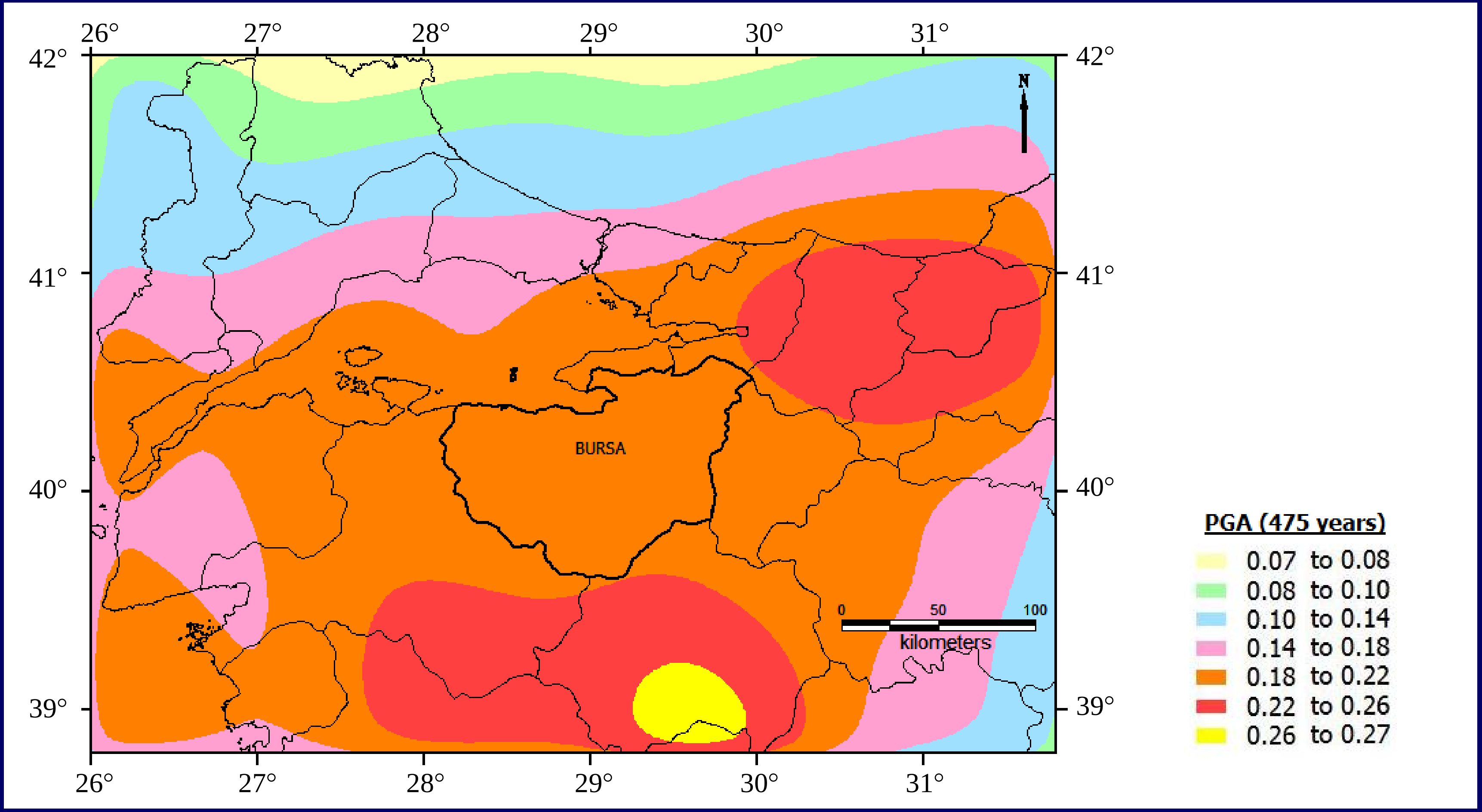
- The seismic hazard values required at every selected grid point for the generation of seismic hazard maps are obtained by using the multi-site analysis module of EZ-FRISK (2005). On the other hand, in the calculation of the contribution of background seismic activity based on the spatially smoothed seismicity model of Frankel (1995), the computer programs of USGS (Frankel et al., 1996) are utilized.

Seismic Hazard Due to Background Seismic Activity

- Contribution of background events to seismic hazard is calculated by using two different models:
  - Spatially smoothed seismicity model of Frankel.
  - Background area source with uniform seismicity.

- Seismic hazard analyses are carried out at all grid points with a spacing of $0.02° \times 0.02°$ in latitude and longitude in the region bounded by 26.0˚- 31.8˚ E longitudes and 38.8˚- 42.0˚ N latitudes to construct seismic hazard maps for PGA corresponding to return periods of 475 and 2475 years.

Seismic Hazard Maps for PGA (in g) Corresponding to the Return Period of 475 Years Obtained by Using Spatially Smoothed Seismicity Model with All Earthquakes (Database Adjusted for Incompleteness)

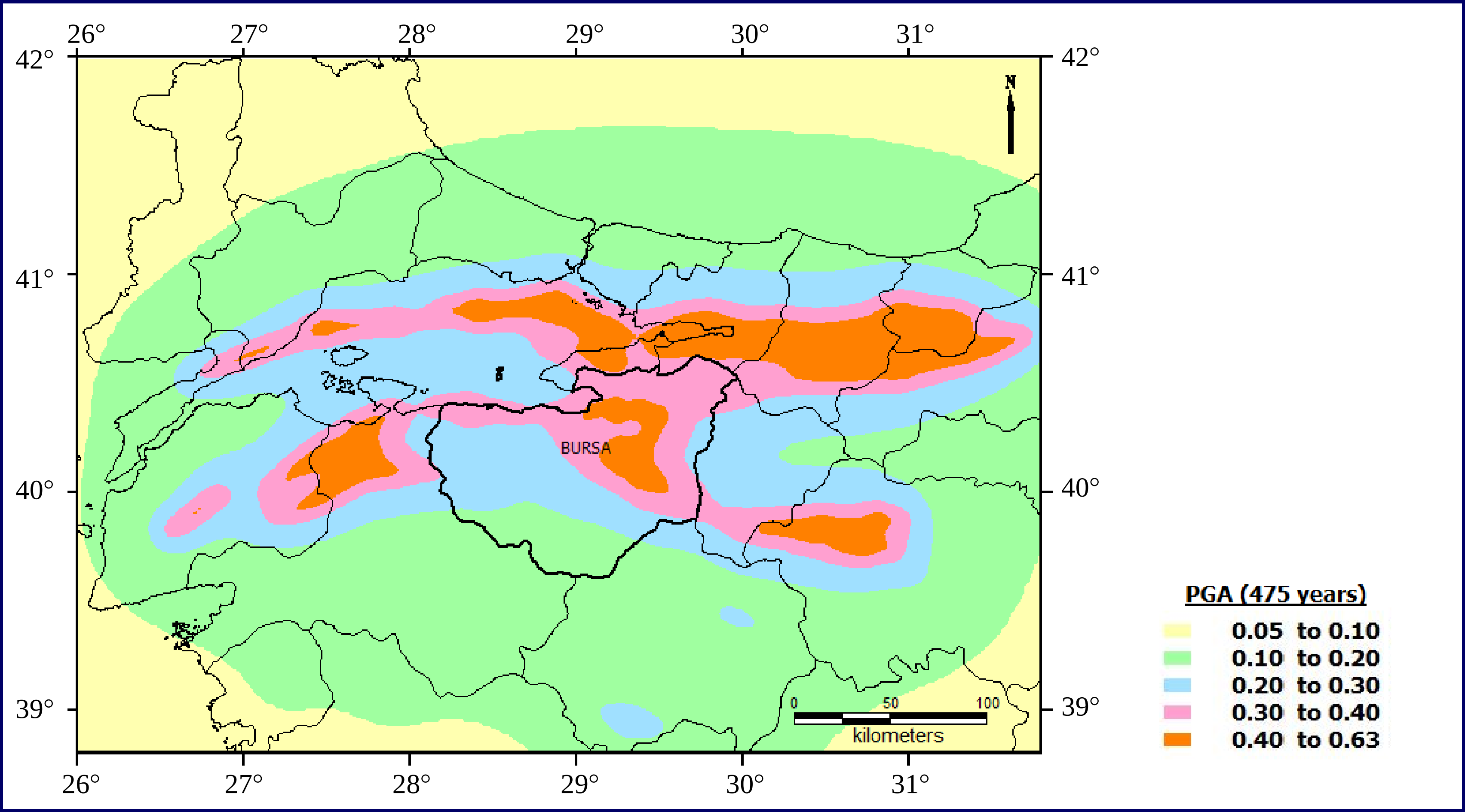


Seismic Hazard Due to Faults

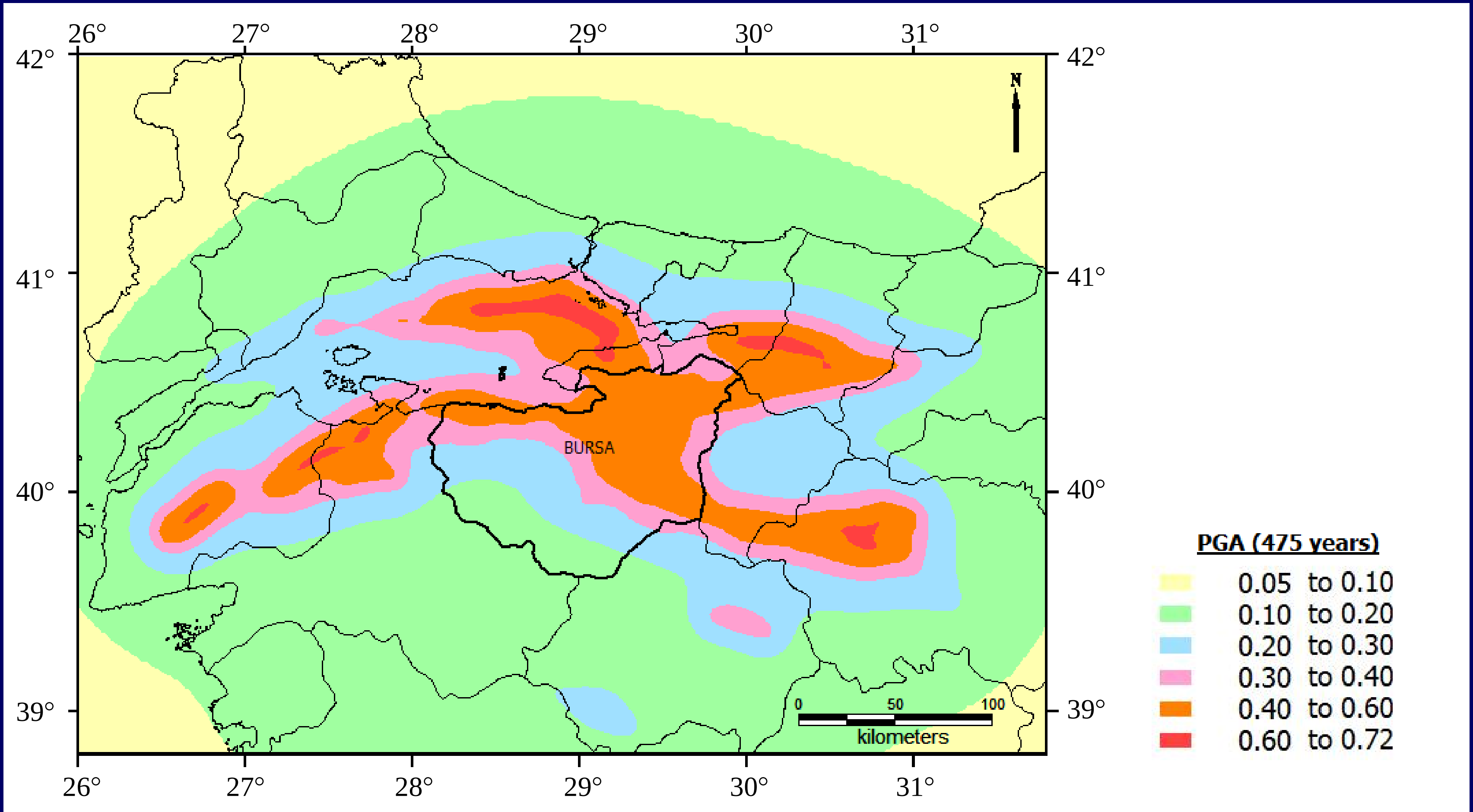
- It is assumed that energy along the faults and fault segments are released by characteristic events that rupture the whole or a large portion of their lengths. Therefore, the maximum magnitudes that the fault segments may generate and their return periods are the main parameters in these computations.

- In order to assess the seismic hazard due to the occurrence of maximum magnitude (characteristic) earthquakes along the fault segments, both the memoryless Poisson and the time dependent renewal models are considered. Brownian Passage Time (BPT) model is used as the probability distribution of inter-event times.

Seismic Hazard Map Obtained for PGA (in g) Corresponding to Return Period of 475 Years (10% Probability of Exceedance in 50 Years) by Considering Only Faults According to the Poisson Model



Seismic Hazard Map Obtained for PGA (in g) Corresponding to Return Period of 475 Years (10% Probability of Exceedance in 50 Years) by Considering Only Faults According to the Renewal Model



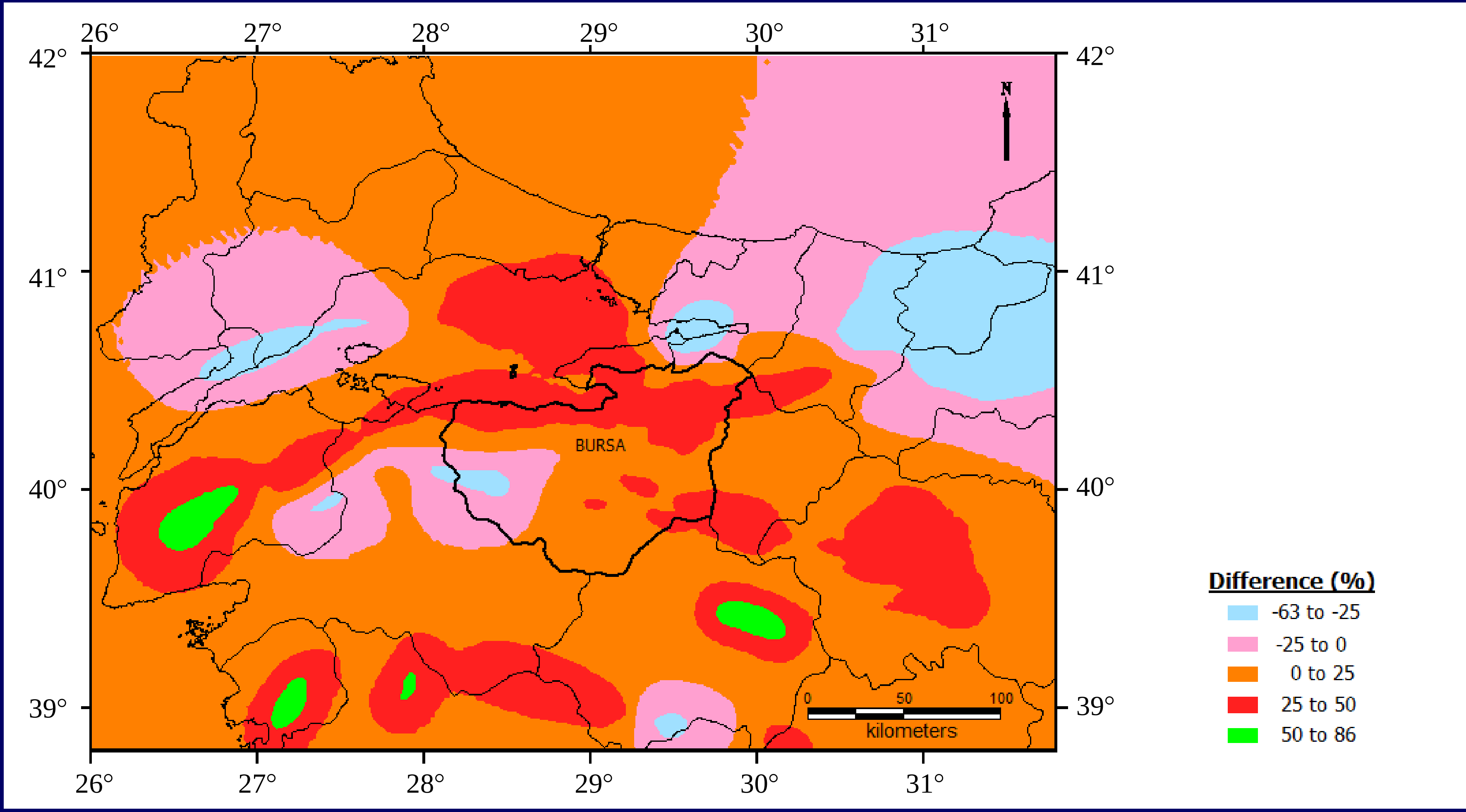
- The difference between the PGA values obtained from Poisson and renewal models is calculated at each grid point by using the following equation;

$$\text{Difference}\ (\%) = \left(\frac{PGA_r - PGA_p}{PGA_p} \right) \times 100$$

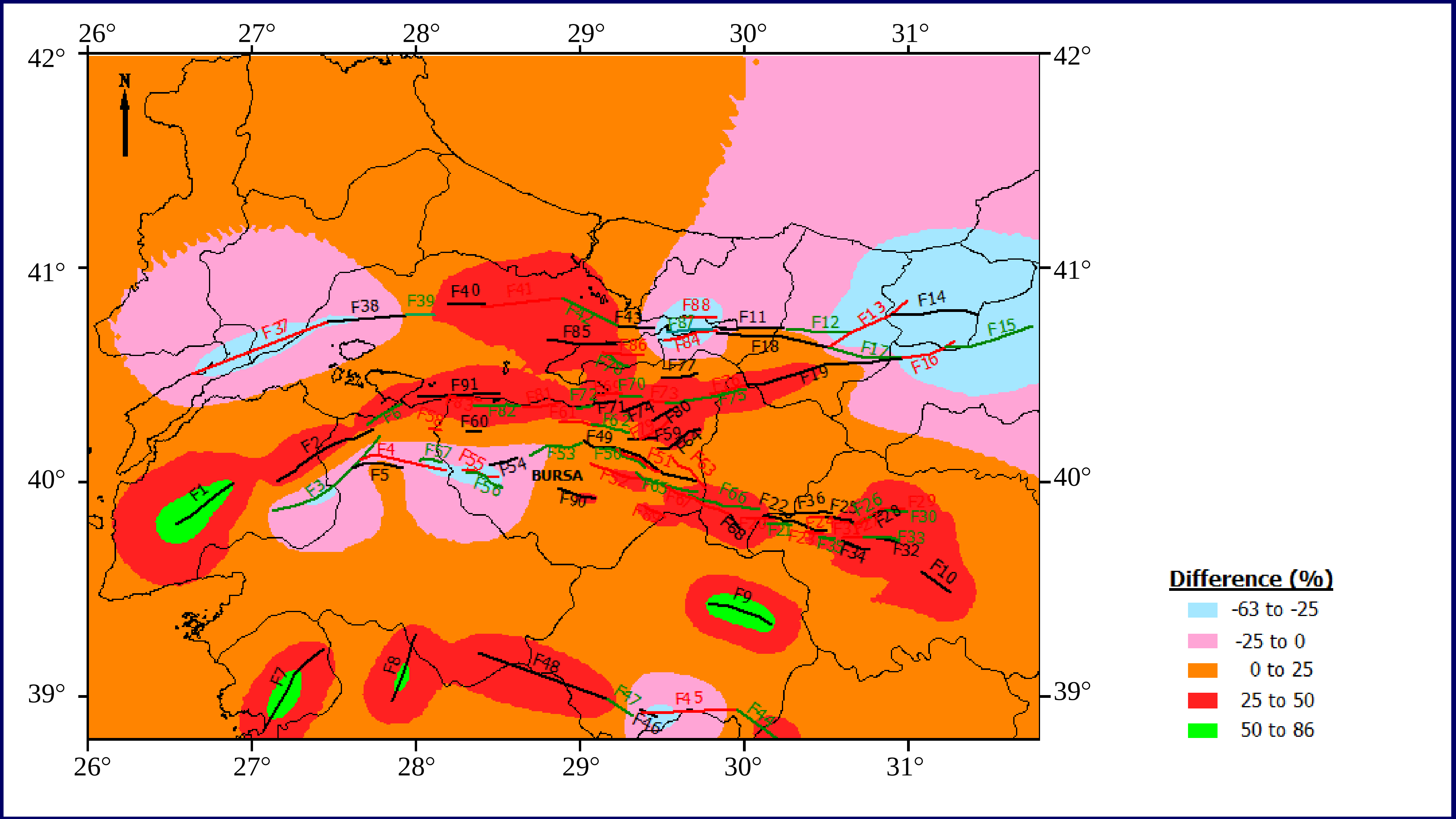
where PGA_r and PGA_p denote the PGA values estimated from renewal and Poisson models, respectively.

- The difference with negative sign (-) means that Poisson model gives higher PGA values than the renewal model and that with positive sign represents the opposite case.

Map Showing the Spatial Variation of the Difference between the PGA Values Obtained from Renewal and Poisson Models for a Return Period of 475 Years



Map Showing the Spatial Variation of the Difference between the PGA Values Obtained from Renewal and Poisson Models for a Return Period of 475 Years and Faults



Best Estimate Seismic Hazard Maps for the Bursa Province

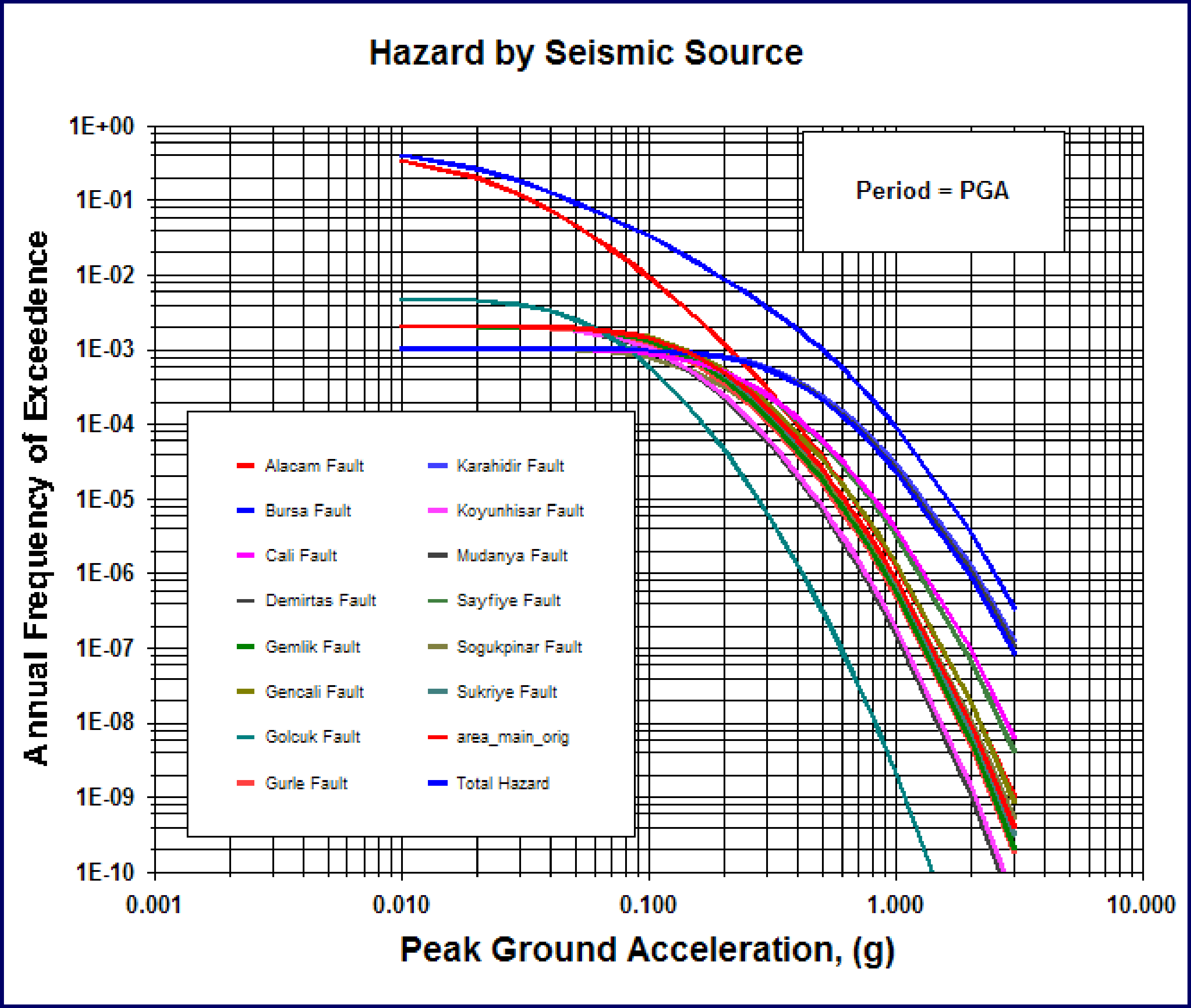
- In computing the contributions of background seismic activity and faults to seismic hazard, different alternative assumptions are considered and seismic hazard analyses are carried out with respect to each one of these assumptions.

- The seismic hazard values obtained for each grid point due to different assumptions are aggregated according to the logic tree format to obtain the best estimate seismic hazard values (consideration of epistemic uncertainties).

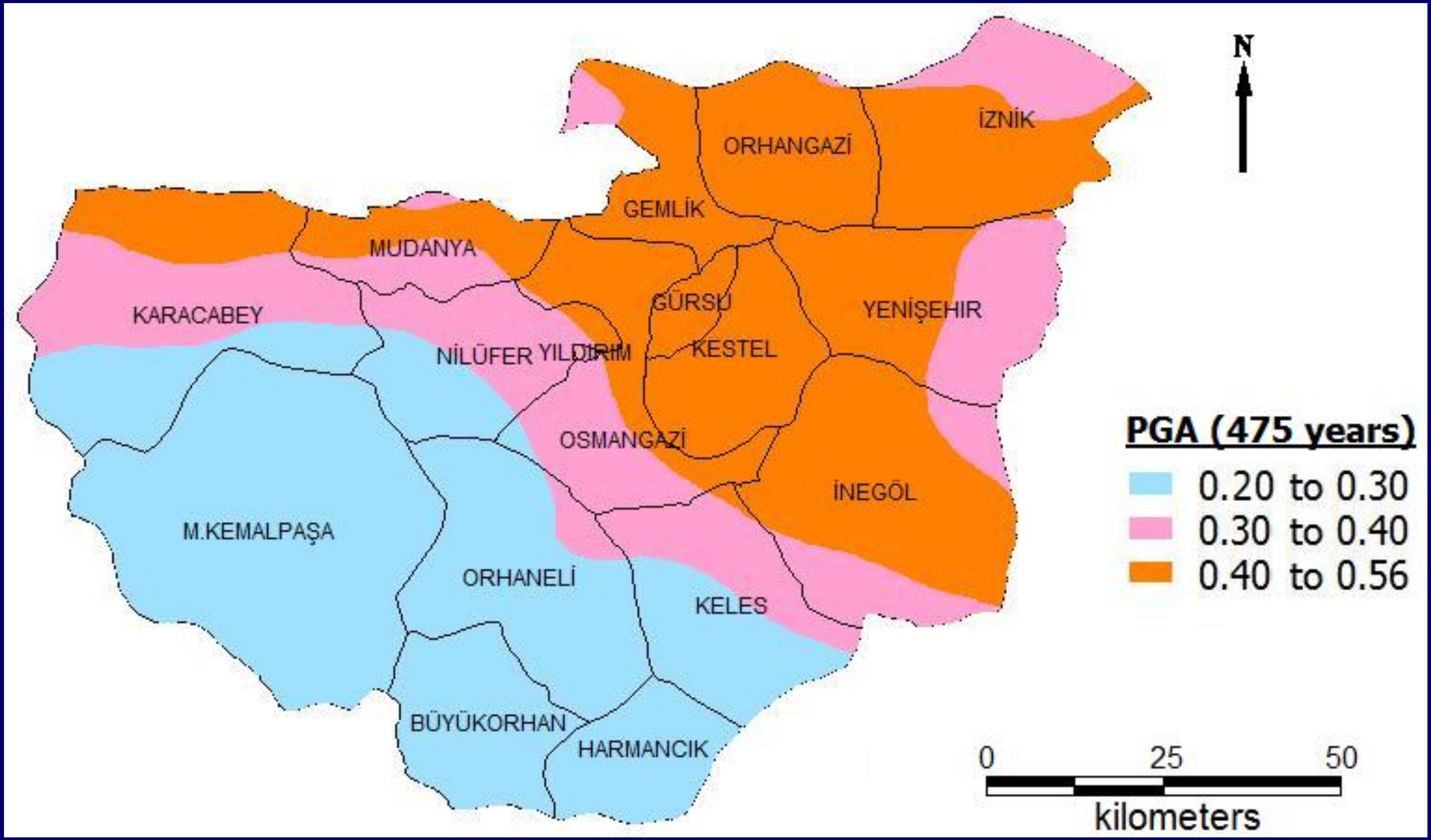
Subjective Probabilities Assigned to Different Assumptions

Source	Alternatives	Subjective Probabilities
Background Seismic Activity	Uniform Seismicity	0.5
	Spatially Smoothed Seismicity	0.5
	The Whole Seismic Database	0.4
	Only Main Shocks	0.6
	Incomplete Seismic Database	0.3
	Artificially Completed Seismic Database	0.7
Faults	Poisson Model	0.3
	Renewal Model	0.7
Attenuation Relationship	Kalkan and Gülkan (2004)	0.5
	Boore et al. (1997)	0.5

Contribution of different seismic sources to the seismic hazard at the city center of Bursa



Best Estimate Seismic Hazard Map for Bursa in Terms of PGA (in g) Corresponding to 10 % Probability of Exceedance in 50 years (475 Years Return Period)



Best Estimate Seismic Hazard Map for Bursa in Terms of PGA (in g) Corresponding to 2 % Probability of Exceedance in 50 years (2475 Years Return Period)