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Regional variations and correlations of Gutenberg–Richter parameters and fractal dimension for the different seismogenic zones in Western Anatolia

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ABSTRACT

We investigated the regional variations of Gutenberg–Richter (G–R) parameters (*a* and *b*) and fractal (correlation) dimension (D_C) and relations among these parameters for the different regions in Western Anatolia (WA). The whole examined area (26–33°E, 33–40.5°N) is divided into 15 different seismogenic regions based on their tectonic and seismotectonic regimes. We used database including 69,182 earthquakes for the instrumental period from 1900 to 2011. We calculated *b* value, which is the slope of the frequency–magnitude Gutenberg–Richter relationship, from maximum likelihood method (ML) and D_C value, which is the slope of $\log_{10}C(r)$ versus $\log_{10}r$, from correlation integral using the least-squares (LS) method. Computed values for 15 different seismogenic regions are mapped using different color scale for different range of values of *b* and D_C. Regional distributions of these parameters reveal information about regional variation of stress level and geological complexity. We concluded Aegean arc and Aegean islands, Aliağa fault and Büyük Menderes Graben the most vulnerable regions for occurrence of the large earthquakes in WA considering the computed lowest *b*-values and the highest D_C-values in these regions. Since D_C/b values are the highest in these regions, this ratio may be used as an indicator of earthquake hazard levels of different seismogenic zones in a studied region. An effort is made to find relationships between the G–R parameters and fractal dimension. We observed negative correlation between D_C and *b* values and positive correlation between D_C and *a*/*b* values for different regions of WA. We observed that the relationship between *a*/*b* and D_C can be used for seismicity, earthquake risk and hazard studies because of the computed high correlation coefficient and fewer scattering of these parameters.

1. Introduction

It is important to identify seismicity properties of any region for studying earthquake risk and hazard studies. A quantitative approach to seismicity analysis can be carried out with the assessment of seismicity parameters: *a* and *b* value, and fractal dimension, D_C. The first two parameters are obtained from frequency magnitude distribution given by Gutenberg–Richter (G–R) relation. The D_C value is estimated using the correlation dimension. The *b*-value is related to the existing proportion between the number of weak and strong events and increase in *b*–value corresponds to a rise in the number of weak events and a decrease in the number of strong events, while a reduction of *b*-value indicates a rise in the number of strong events and a decrease in weak events. The D_C–value characterizes the level of spatial events homogeneity. The less the value of the fractal dimension, the more located are the events; that is a decreasing of D_C corresponds to a grouping of the events. The spatial variation of *b* values is related to the distribution of stress and strain (Mogi, 1967; Scholz, 1968), geological complexity (Lopez Casado et al., 1995), material heterogeneity or crack density (Mogi, 1962) and velocity of deformation (Manakou and Tsapanos, 2000). D_C is controlled by the heterogeneity of the stress field and the preexisting geological, mechanical or structural heterogeneity (Öncel et al., 1996). So, it is important to understand the G–R relation and fractal dimension of seismicity in assessing the earthquake hazard of a tectonically active region.

The Aegean extension region is one of the most seismically active and rapidly prolongating areas of the Eastern Mediterranean region (Bozkurt, 2001). The large and destructive earthquakes occurred in both historical and instrumental periods in this region. So, this region has been attractive for earthquake hazard and risk studies. In order to estimate the earthquake hazard in and around WA, several earthquake hazard studies (e.g. Papazachos, 1999; Polat et al., 2008; Sayıl and Osmanşahin, 2008; Bayrak et al., 2005, 2009) have been performed in terms of the G–R relation. Also

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several fractal studies (Öncel et al., 1995, 1996; Öncel and Wilson, 2002; Öncel, 2004; Ceylan, 2006; Polat et al., 2008) have been performed in order to estimate the spatial, regional or temporal variation of D_C value in and around Turkey. It is important to understand the G–R relation and fractal dimension of seismicity in assessing the earthquake hazard of a tectonically active region. The relationship between the b and D_C values of earthquakes is a widely discussed topic during the last three decades (e.g. Aki, 1981; King, 1983; Turcotte, 1986; Hirata, 1989; Wang, 1991; Öncel et al., 1996; Henderson et al., 1999; Legrand, 2002; Wyss et al., 2004; Mandal and Rastogi, 2005). Both the positive (e.g. Guo and Ogata, 1995; Legrand, 2002; Pascua et al., 2003; Öncel and Wilson, 2004) and negative (e.g. Hirata, 1989; Henderson et al., 1994; Öncel et al., 1996; Wang and Lee, 1996) correlations between those two scaling exponents have been reported and debated in the literature. In some cases (e.g. Henderson et al., 1999; Mandal and Rastogi, 2005; Mandal et al., 2005), the correlation could even change from a negative one to positive.

In the present study, we computed the values of a, b and D_C for 15 different seismogenic source zones in WA to determine earthquake hazard potential from seismicity analysis for the instrumental period earthquakes. We mapped these parameters for different range and color scale. We interpreted these values considering with seismicity, tectonic and seismotectonic properties of the regions. Also, we correlate these parameters using Least Squares (LSs) method.

2. Tectonics

Main tectonic structures playing the important role in the geodynamics evolution of the Aegean region are the Aegean Arc and Western Anatolian Extension Zone. The convergence between the Arabian and Eurasian plates in the Eastern Anatolia pushes the Anatolian Plate westward along the North Anatolian Fault Zone and the East Anatolian Fault Zone and Anatolian Plate rotates anti clockwise with an average velocity of 24 mm/yr (McClusky et al., 2000). This motion is transferred into the Aegean in the southwestern direction (McKenzie, 1972, 1978), which results in the northern Aegean being dominated by dextral strike-slip faulting of northeastern strike. The African Plate subducts beneath the Anatolian Plate in an N-NE direction in the Eastern Mediterranean (McKenzie, 1978). The Aegean arc consists of the outer sedimentary arc and of the inner volcanic arc, while its outer borders are bounded by the Aegean trench with a maximum water depth of 5 km (Papazachos and Kiratzi, 1996). The Western Anatolian is one of the most seismically active and rapidly extending areas in the world (e.g., Bozkurt, 2001). It is currently experiencing an approximately N–S continental extension at a rate of 30–40 mm/year (Oral et al., 1995; Le Pichon et al., 1995).

Approximately E–W trending grabens (e.g. Edremit, Bakırçay, Kütahya, Simav, Gediz, Küçük Menderes, Büyük Menderes, and Gökova grabens) and their basin-bounding active normal faults are the most prominent neotectonic features of Western Anatolia (e.g., Şengör et al., 1985; Şengör, 1987; Seyitoğlu and Scott, 1992; Seyitoğlu et al., 1992; Koçyiğit et al., 1999; Yılmaz et al., 2000; Lips et al., 2001; Sözbilir, 2001, 2002; Bozkurt and Sözbilir, 2006; Kaya et al., 2004; Erkul et al., 2005; Emre and Sözbilir, 2007).

The eastern part of studied region includes the NW–SE trending Dinar, Beyşehir, and Akşehir–Afyon grabens and NE–SW trending Burdur, Acıgöl, Sandıklı, Çivril and Dombay ova grabens and their bounding faults (e.g., Bozkurt, 2001). The existence of two sets of normal faults indicates that the region is extending biaxially, with both NE–SW and NW–SE components of extension (Westaway, 1994). Barka et al. (1997) suggested that the NE–SW trending left-lateral Fethiye–Burdur Fault Zone (FBFZ), which is interpreted as the northeastern continuation of the Pliny–Strabo Fault Zone on the land, and the Eskişehir Fault forms the major boundary between the Western Anatolian extensional province and the Isparta Angle area. GPS measurements indicate slip rates of 1.5 cm year^{-1} along the FBFZ (Reilinger et al., 1997; Barka and Reilinger, 1997). The recent GPS studies, the distribution of historical and instrumental earthquakes, and morphological features indicate that the FBFZ is active.

The N–S-striking active normal faults and some NNE–SSW-trending strike-slip faults such as the Orhanlı Fault Zone (OFZ) and the Bergama-Zeytindağ Fault (BZF) zone are also present in the region (Yılmaz et al., 2000; Uzel and Sözbilir, 2008). The most continuously traceable fault is the OFZ. Other potentially active faults are the Manisa Fault near Manisa city, and İzmir Fault (İF) trending E–W direction (Bozkurt and Sözbilir, 2006). Gökova Fault (GF) can be traced on a line trending E–W direction along the northern coast of the Gökova Bay (GB) at the south of Western Anatolian (e.g., Şaroğlu et al., 1992; Eyidoğan, 1988; Ocakoğlu et al., 2004; Ocakoğlu et al., 2005; Aktuğ and Kılıçoğlu, 2006).

3. Data and source zonation

The instrumental database covering between 1900 and 2011 is used in this study. The data was compiled from different sources and catalogs, which are TURKNET, International Seismological Centre (ISC), Incorporated Research Institutions for Seismology (IRIS) and The Scientific and Technological Research Council of Turkey (TUBITAK). The catalogs include different magnitude scales (m_b – body wave magnitude, M_S – surface wave magnitude, M_L – local magnitude, M_D – duration magnitude, and M_W – moment magnitude), the origin time, epicenter and depth information of earthquakes. The earthquakes from 1900 to 1974 were obtained from the International Seismological Centre (ISC) and instrumental catalog of KOERI. Turkey earthquake catalog starting from 1974 until 2010 was taken from the Boğaziçi University, Kandilli Observatory and Earthquake Research Institute (KOERI).

An earthquake data set used in seismicity or earthquake hazard studies must certainly be homogenous, in other words, it is necessary to use the same magnitude scale. However, the earthquake data obtained from different catalogs have been reported in different magnitude scales. So, all earthquakes must be defined in the same magnitude scale. Bayrak et al. (2009) developed some relationships between different magnitude scales (m_b – body wave magnitude, M_S – surface wave magnitude, M_L – local magnitude, M_D – duration magnitude, and M_W – moment magnitude) in order to prepare a homogenous earthquake catalog from different data sets. We prepared a homogeneous earthquake data catalog for M_S magnitude using these relationships. Although the scale of M_W usually is used in the seismic hazard studies, we prefer M_S magnitude in this study. Hanks and Kanamori (1979) determined that M_W is calculated quite similar to M_S for a number of earthquakes with $M_S \leqslant 8.0$. A large part of the earthquakes in the catalogs used in this study are reported in the scale of M_S. In addition, we have used M_S magnitudes since no earthquake with $M_S > 8.0$ have occurred in the study area for the instrumental period.

It is necessary to consider seismicity, tectonics, geology, paleoseismology, and other neotectonic properties in a region for an ideal characterization of seismogenic source zones. Several authors defined different seismogenic source zones to study seismic hazard of Turkey (e.g., Alptekin, 1978; Erdik et al., 1999; Kayabalı, 2002; Bayrak et al., 2005, 2009). Bayrak et al. (2009) used different 24 source regions considering the different previous zonation studies for modeling of earthquake hazard in Turkey and 9 seismic source zones in these 24 regions are related to WA. Bayrak and Bayrak (2011) updated the regions used by before Bayrak et al. (2009)