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Comments on "An investigation of seismicity for western Anatolia" by Sayıl and Osmanşahin (2008)

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Numerous local or regional seismic hazard studies have been made to estimate the seismic hazard in and around Turkey using the statistical processing of historical and instrumental earthquake data. One of the most popular methods is the Gutenberg–Richter (G–R) law. Also, the knowledge of return period is of great importance in studying and analyzing earthquake hazard and/or seismicity. Such kind of reliable studies strongly depend on (i) selecting a studied area suitable with seismotectonics, (ii) preparing a homogenous catalogue including a large number of earthquakes, and (iii) making a comprehensive completeness analysis and selecting a suitable cut off magnitude, which should be done for each region separately if one studies several seismic zones whose seismotectonics characteristic are different, (iv) selecting a method suitable with data. The accurate estimation of a and b parameters of G–R is of primary importance because the evaluations of the seismicity depend on them. One of the most recent studies on statistical earthquake occurrence can be found in the paper of Sayıl and Osmanşahin (2008).

In their study, Sayıl and Osmanşahin (2008) used G–R magnitude–frequency relation to investigate the seismicity of western Anatolia. They computed the recurrence periods for the 13 sub-regions of the limited area between 36°–40° N and 26°–32° E. Seismic source zones or sub-regions of an area are widely used to determine the earthquake hazard and earthquake risk of any area in the world. Seismic source zones are determined with two fundamental tools: a seismicity profile and the tectonic structure of the region under consideration (Erdik et al. 1999). Since Turkey is located in a very active seismic area, several studies have investigated the seismic hazard and seismic risk considering different seismic zones in and around Turkey (Alptekin 1978; Yaltırak et al. 1998; Erdik et al. 1985, 1999; Papaioannou and Papazachos 2000; Jiménez et al. 2001; Kayabalı 2002; Karavos et al. 2003; Bayrak et al. 2005). Although the authors in all of these studies or other authors studying seismic hazard in different areas of the world use polygonal or rectangular seismic zones according to fault geometries and space distribution of earthquakes, Sayıl and Osmanşahin (2008) preferred to use elliptical seismic zones. I think that their sub-regions are not more realistic for studying seismicity of western Anatolia because the

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geometries of faults and graben systems in western Anatolia are suitable to the use of polygonal seismic zones. Also, in the case of using elliptical seismic zones, earthquakes that occurred outside the considered fault system are joined to a studied seismic zone.

An earthquake data set used in the assessment of earthquake hazard or seismic risk must be homogenous; in other words, it is necessary to use the same magnitude scale. The earthquake data taken from different catalogues, are provided in different scales. For a great number of earthquakes, there is more than one value, sometimes in different magnitude scales. To prepare a homogeneous earthquake catalogue some new relationships are developed between the different magnitudes scales (m_b, M_S, M_L, M_D, etc.). Sayıl and Osmanşahin (2008) developed only two relationships between m_b–M_S and I_0 (intensity)–M_S to prepare a homogenous catalogue of M_S. We know that there are several earthquakes of which only M_D or M_L magnitudes are given in Turkish catalogues. I think that their catalogue is not complete because they do not take into account the earthquakes whose values of I_0, m_b or M_S are not known.

The standard least squares method (LSE) is based on the assumption that the values on only one axis (horizontal or vertical) are estimated without errors. In particular, in preparing a homogenous earthquake catalogue, both horizontal and vertical axes include errors. Bayrak et al. (2005) applied the orthogonal regression method, one of the most widely known techniques for errors-in-variables estimation in the simple linear regression model, to prepare a homogenous earthquake catalogue of M_S in and around Turkey. Castellaro et al. (2006) applied orthogonal regression to magnitude scale conversion, which is a common problem in seismology, with important implications in seismic hazard evaluation, and analyzed it through specific tests. Their analysis concluded that the commonly used LSE method may induce systematic errors as high as 0.3–0.4 in magnitude conversion, and, even more importantly, this can introduce apparent catalogue incompleteness, as well as a heavy bias in estimates of the slope of frequency–magnitude distributions. Sayıl and Osmanşahin (2008) computed relationships between m_b–M_S and I–M_S using the LSE method to prepare a homogenous catalogue of M_S

$$M_S = 1.40m_b - 2.33 \quad (1)$$

$$M_S = 0.47I_0 + 2.05 \quad (2)$$

I think that their homogenous catalogue prepared from Eqs. 1 and 2 may include systematic magnitude errors as high as 0.3–0.4 unit (Castellaro et al. 2006) and that it will effect *a* and *b* values of G–R relationship, which they used to assess earthquake recurrences. Also, since they consider 13 different seismic zones that have different tectonic and seismotectonic properties to study the seismicity of western Anatolia, they have to develop relationships between different magnitude scales for each seismic zone.

In seismicity studies, it is frequently necessary to use the maximum number of events available for high-quality results. It is well known that magnitude completeness changes with time in most catalogues and usually decreases. So, the minimum magnitude of complete recording is an important parameter for such studies related to seismicity and magnitude completeness is necessary for a reliable estimation of various seismic parameters. Sayıl and Osmanşahin (2008), who did not make a reliable completeness analysis for the catalogue used in their study, such as that given in Table 1, selected a minimum magnitude (cut off magnitude) of $M_{min} = 4.0$ for all sub-regions of western Anatolia and for both historical and instrumental periods. It is not meaningful to select this cut off magnitude value, especially for historical catalogues including earthquakes in and around Turkey. An earthquake catalogue for the Aegean and surrounding area covering western

Table 1 The results of completeness analysis for the Aegean and surrounding area catalogue compiled by Papazachos et al. (1997), Papazachos (1999), and Papaioannou and Papazachos (2000)

Time period	Cut off magnitude
550 B.C.–1995 A.D.	$M \geq 8.0$
1500–1995	$M \geq 7.3$
1845–1995	$M \geq 6.5$
1911–1995	$M \geq 5.5$
1950–1995	$M \geq 5.0$
1970–1995	$M \geq 4.5$

Anatolia has been published by Papazachos et al. (1997) for the period 550 B.C. to 1995 A.D. Papazachos (1999) and Papaioannou and Papazachos (2000) made a comprehensive completeness analysis for this catalogue and found the results listed in Table 1. It is not possible to find a cut off magnitude of 4.0 in western Anatolia for both historical and instrumental periods, because western Anatolia covers a smaller area than the area studied by Papazachos et al. (1997). Sayıl and Osmanşahin (2008) made a completeness analysis and listed their results in Table 4 (in their paper). For example, they found that their data is complete since 1862 for $M \geq 4.0$ in region 4 covering Bolvadin–Afyonkarahisar. When the results in Table 1 are considered, it is not possible to imagine this for a very small Bolvadin–Afyonkarahisar region including only 31 earthquakes. The results listed in Table 1 show that Sayıl and Osmanşahin (2008) did not make a comprehensive completeness analysis and selected a wrong cut off magnitude. Also, since they consider 13 different seismic zones, which have different tectonic properties to study seismicity of western Anatolia, they have to make a comprehensive completeness analysis for each seismic zone. Therefore, the cut off magnitudes for each region will be different. As a result, seismicity parameters calculated by them will include systematic errors due to the selected cut off magnitude.

The Gutenberg and Richter (1944, 1954) relationship known as magnitude–frequency relationship (MFR)

$$\log N = a - bM \tag{3}$$

has been widely used in research on seismicity and seismic risk analysis. For a certain region and time interval, Eq. 3 provides the number of earthquakes N with magnitude, M, where a and b are real constants. a describes the seismic activity (log number of events with $M = 0$). It is determined by the event rate and for certain regions, depends upon the volume and time window considered. b, which is typically close to 1, is a tectonic parameter describing the relative abundance of large to small shocks. The b value calculated for a set of earthquake magnitudes may depend strongly on the fitting technique used. Gutenberg and Richter used the method of least squares to estimate the parameters in their frequency–magnitude relation. Weichert (1980) points out that the basic assumption of independent, identically distributed random variables usually made in least-squares analysis is violated for the cumulative event counts [$N(M)$ in (1)]. A discussion of generalized least-squares estimation of b values can be found in Guttorp (1987). Utsu (1965) proposed a different estimate of the b value, which was shown by Aki (1965) to be a maximum likelihood estimate (MLE) for a particular exponential model that can be derived from (3). LSE fits to Eq. 3 tend to statistically estimate a very low a b value, because they cannot include magnitudes above the maximum observed. Estimated b values may be very different when different fitting techniques are used. Implicit assumptions regarding maximum magnitude and the treatment by different techniques of

zero observations in a magnitude interval may significantly affect the calculated *b* value, especially when the data sample is small. MLE for exact or continuous magnitudes gives biased results if applied to interval data, with the bias increasing as interval size increases (Bender 1983). It is suggested that estimation of recurrence parameters in the MFR should always employ a maximum likelihood method, and the method gives the necessary extension of known results to the important case of unequal periods of observation (Weichert 1980). Sayıl and Osmanşahin (2008) used simple LSE to fit to the distributions of magnitude–frequency they observed for different 13 seismic sources in western Anatolia. The data used in their study include both historical and instrumental data. If they make a comprehensive completeness analysis, they may see that the catalogue has zero observations in some time periods. Their regions include too few data, e.g. 32 earthquakes in region 1, 31 earthquakes in region 4 and 39 earthquakes in region 13. Fitting a straight line such as that implied by the G–R law through recurrence data in which the mean rate of exceedance of small earthquakes is underestimated, will tend to flatten the line. As a result, the actual mean rate of small earthquakes will be underpredicted and the mean rate of large earthquakes will be overpredicted (Slejko 2006). Since it is necessary to have plenty data for LSE, the computed *b* values from LSE will contain extreme errors for the regions having too few data. I think that they found very small *b* values because of selected method and used data. In my opinion, MLE should be more appropriate for their data. Also, there are a lot of methods in the literature that combine both historical and instrumental data and permit a combination of the largest historical data with complete instrumental data of variable threshold magnitudes.

The *b* value for a region not only reflects the relative proportion of the number of large and small earthquakes in the region, but is also related to the stress condition over the region. Many factors can cause perturbation of the normal *b* value. On average, *b* value is near unity for most seismically active regions on Earth (e.g. Frohlich and Davis 1993). However, a detailed mapping of *b* value often reveals significant deviations. The spatial variation of *b* values is related to the distribution of stress and strain (Mogi 1967; Scholz 1968). On the other hand, high *b* values are reported from areas of increased geological complexity (Lopez Casado et al. 1995), indicating the importance of multifracture area. Thus, low *b* value is related with low degree of heterogeneity, large stress and strain, large velocity of deformation and large faults (Manakou and Tsapanos 2000). *b* values were first estimated by Gutenberg and Richter (1944, 1954) for various regions of the world. They suggested that *b* values range from 0.45 to 1.50, while Miyamura (1962) found that *b* values change from 0.40 to 1.80 according to the geological age of the tectonic area. Global seismicity has been studied by several authors and it has been found that *b* values vary between 1.0–1.6 (Mogi 1962), 0.8–1.2 (McNally 1989), 0.6–1.5 (Udias and Mezcua 1997) and 0.53–1.19 (Bayrak et al. 2002). Sayıl and Osmanşahin (2008) calculated the *b* values changing between 0.42 and 0.66 for 13 different regions in western Anatolia. These values are too low and around the minimum *b* level computed for the global earthquakes. Since the seismicity in western Anatolia related to graben systems is high and displays swarm-type activity with remarkable clustering of low-magnitude earthquakes in time and space (Üçer et al. 1985; Eyidoğan 1988), it is not possible to compute such a very low *b* values for this area. Sayıl and Osmanşahin (2008) did not compare their results with the other studies given in literature for western Anatolia and did not discuss the tectonic and seismotectonic properties of western Anatolia. Papaioannou and Papazachos (2000) studied *b* values in detail for the Aegean and surrounding and found that the values change between 0.83 and 0.89 for the different regions of western Anatolia covering the same regions used by Sayıl and Osmanşahin (2008) for both historical and instrumental periods. Papazachos (1999) mapped *b* values for Greece and surrounding area and observed that the values vary between 0.8 and 1.0 for western Anatolia.

Jenny et al. (2004), for the period 550 B.C. to 1995 A.D., computed b value equal to 1.00 and Bayrak et al. (2005) computed b value equal to 1.01 for instrumental time period for western Anatolia. b values computed by Sayıl and Osmanşahin (2008) were lower than those for western Anatolia given in literature by several researchers. I think these low values are related to their data and used simple LS method. If they discussed their results with the former studies given above and seismotectonics of western Anatolia, they might have seen that the results were absolutely inaccurate.

Earthquake recurrence times (return periods) can be evaluated from paleoseismic observations, patterns of seismicity and strain rates measured from GPS networks. Sayıl and Osmanşahin (2008) calculated recurrence periods and occurrence risk in T years of an earthquake with any magnitude M depending on a and b values of G–R. Since they computed too low b values for the different regions of western Anatolia, it is not possible to expect the return periods and occurrence risks computed by them. For example, they found that the return period of an earthquake magnitude equal to 7.0 is 67 years. Jenny et al. (2004) computed the return periods between 100 and 700 years like this size for earthquakes for the different regions of western Anatolia from seismic and geodetic strain rates.

Another problem of Sayıl and Osmanşahin (2008) is very clear. They showed the model of plate tectonics of Anatolia and surrounding area referred to The Institute of Mineral Research and Exploration (MTA) in their Fig. 1. On the contrary, Sayıl (2005) referred to KOERI (Boğazici Univ., Kandilli Observatory and Earthquake Res. Enst., Istanbul, Turkey) for the same tectonic map. We know that Şaroğlu et al. (1992) studied only the active faults in the landside of Turkey for MTA. Sayıl and Osmanşahin (2008) took the velocities of plates from Global Positioning System data (GPS) and the tectonics outside of Turkey and surrounding area from other sources but they did not refer to these studies. These plate velocities given in their study are presented in literature by McClusky et al. (2000) for GPS observations.

As far as I see, the paper of Sayıl and Osmanşahin (2008) is completely unreliable. Their results are not in accordance with works in the literature. Also, these results do not reflect the seismotectonic properties of western Anatolia. This is due to the fact that (i) they did not form sub-regions suitable with the geometrics of the fault systems in the region, (ii) they did not compile an appropriate homogenous catalogue, (iii) they did not make a comprehensive completeness analysis and did not select correct values of cut off for each region, (iv) although there are a lot of methods in the literature, which combine both historical and instrumental data and are suitable with their data including zero observations in some time intervals, they preferred the simplest least square method. I am afraid that such an unfair study could mislead seismologist and engineers dealing with seismic risk and seismic hazards in western Anatolia. It is very difficult for me to see why this work is accepted for publication. I think this study has no scientific contribution and it looks like an application of undergraduate level.

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