Eastern Anatolian Journal of Science
Volume I, Issue I, 2015, 01-09

Eastern Anatolian Journal of Science

An Evaluation of Earthquake Hazard Parameters in and around Ağrı, Eastern Anatolia, Turkey

YUSUF BAYRAK[1], AYSE NUR ATMIŞ[1], FATMA TEMELLİ[1], HIWA MOHAMMADI[2], ERDEM BAYRAK[3], ŞEYDA YILMAZ[3], TUĞBA TÜRKER[3]

[1] Ağrı İbrahim Çeçen University, Ağrı, Turkey
[2] Shiraz University, Department of Earth Sciences, Iran
[3] Karadeniz Technical University, Department of Geophysics, Trabzon, Turkey

Abstract

The earthquake hazard parameters of *a* and *b* of Gutenberg-Richter relationships, return periods, expected maximum magnitudes in the next 100 years and probabilities for the earthquakes for certain magnitude values are computed using the earthquakes occurred between 1900 and 2014 years in and around Ağrı. The relation of *LogN=4.73-0.68M* is calculated for the studied area. The mapping of *b* values show that the regions in the east and southeast of Ağrı, east of Horasan and around Patnos where low *b* values are computed have high stress levels and capacity to generate large earthquakes in the future. It is found that earthquakes larger than 5.5 may be occurred in the regions where *b* values lower than 0.8 have been observed in the next 100 years. The return periods for magnitudes between 5.0 and 7.3 are estimated between 5 and 176 years in the studied area, respectively. The probabilities of an earthquake with *M*=6.0, 6.5 and 7.0 in the next 100 years are computed 99%, 86% and 59%, respectively. The largest earthquake occurred in the studied area is 7.3 and its occurrence probability is 43% in the next 100 years. The faults around Ağrı are seismically active and have potential for an earthquake larger than 6.0. Since the sediment basin of Ağrı is very young and alluvial layer is tick, there is very high hazard on the buildings and human's life in Ağrı.

Keywords: b values, return period, expexted maxium, magnitude, Ağrı, Eastern Anatolia.

1. Introduction

The region in and around Ağrı (42.0-44.2 °E and 39.0-40.5 °N) covers seismically tectonic features such as Ağrı Fault, Bulanık Fault, Çaldıran Fault, Ercis Fault, Horasan Fault, Çobandede Fault Zone, Iğdır Fault, Malazgirt Fault, Balıklıgölü Fault Zone, Kağızman Fault Zone, Doğubayazıt Fault Zone, Karayazı Fault and Tutak Fault Zone. Since these faults produce some large earthquakes (04 April 1903 Malazgirt (M=6.3), 13 September 1924 Pasinler (M=6.8), 24 November 1976 Çaldıran (M=7.3) and 30 October 1983 Horasan–Narman (M=6.8) during instrumental earthquake time period, it is very important to reveal earthquake hazard and risk in the area (BOZKURT 2001).

Many quantitative methods have been applied over the years to estimate seismicity in various regions of the world. Several local and regional seismic hazard studies (ASLAN 1972; BATH 1979; YARAR *et al.* 1980; ERDIK *et al.* 1999; KAYABALI and AKIN 2003; BAYRAK *et al.* 2005; 2009) have been performed in order to estimate the seismic hazard in Turkey using the statistical processing of instrumental earthquake data.

The most popular method used is the frequency-magnitude relationship of Gutenberg-Richter (G-R). A large number of studies on *a* and *b* parameters of G-R relationship have been presented since Gutenberg and Richter introduced their law about the earthquake magnitudes distribution. The different methods such as least square (LS) or maximum likelihood estimation (MLE) can be applied to compute these parameters which are very important in earthquake hazards and risk studies. The different hazard parameters such as the mean return period for an earthquake occurrence, the most probable maximum magnitude of earthquakes in a certain time interval and the probabilities for the large earthquakes occurrences during certain times using the parameters of G-R relationships. BAYRAK *et al.* (2015) applied this method to the different regions of the East Anatolian Fault.

Aim of this study is to evaluate the earthquake hazard in and around Ağrı in terms of different hazard parameters. For this purpose, the mean return period, expected maximum magnitude of earthquakes in the next 100 years and the probabilities for the large earthquakes occurrences in the next 25, 50 and 100 years are computed from the parameters of G-R relationships using MLE.

Accepted date: 15.04.2015
Corresponding author:
Yusuf Bayrak, PhD
Agri İbrahim Çeçen University, Ağrı, Turkey
E-mail: ybayrak@agri.edu.tr

2. Data

The database used was compiled from different sources and catalogs such as Turkey National Telemetric Seismic Network (TURKNET), Incorporated Research Institutions for Seismology (IRIS), the International Seismological Centre (ISC) and The Scientific and Technological Research Council of Turkey (TUBITAK) and is provided in different magnitude scales. The catalogs include different magnitudes 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.

An earthquake data set used in seismicity or seismic 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. Therefore, all earthquakes must be defined in the same magnitude scale. BAYRAK *et al.* (2009) developed some relationships among 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 homogenous earthquake data catalog for M_s magnitude using relationships and have considered only instrumental part of the earthquake catalogue (1900-2014). Finally, the catalog includes 1569 earthquakes with $M_s \geq 1.1$. The graphs of magnitude-earthquake number and years-cumulative earthquake number are shown in Figure 1. The recorded earthquake numbers have increased after 1976 depending on installed seismograph stations in the studied area. Also, a large amount of magnitude of recorded earthquakes are lower than 4.0 and the size of nine earthquakes are larger than 6.0.

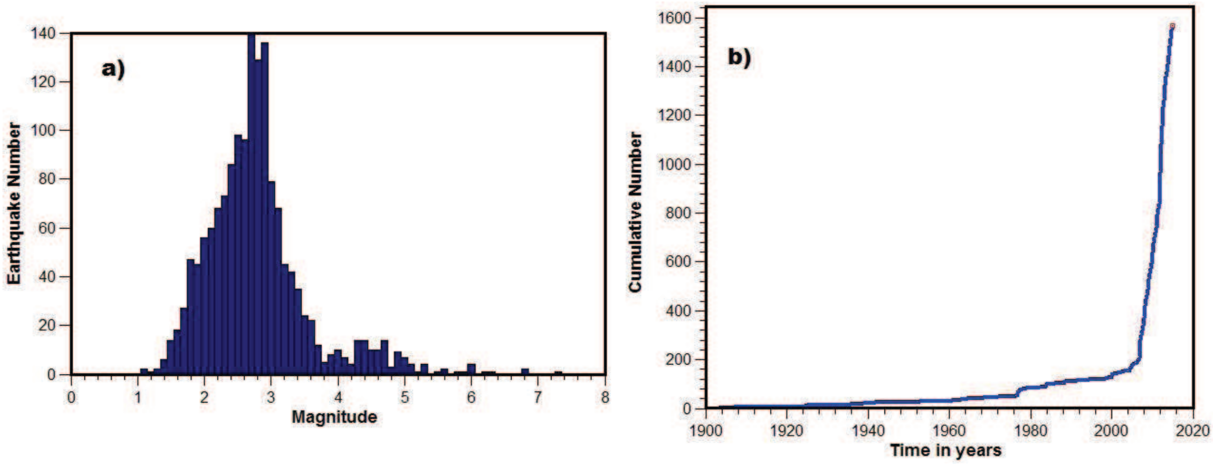

Figure 1. The graphs of, a) Earthquake number versus magnitude and b) cumulative number versus time for earthquakes in and around Ağrı

3. Tectonics and Seismicity

The neotectonic evolution of the eastern Anatolian region has been dominated by the collision of the Arabian plates with the Eurasian plate along the Bitlis-Zagros suture zone (Figure 2). The eastern Anatolian contractional province including the eastern Anatolian high plateau and the Bitlis-Pötürge thrust zone consists of an amalgamation of fragments of oceanic and continental crusts that squeezed and shortened between the Arabian and Eurasian plates. This collisional and contractional zone is being accompanied by the tectonic escape of most of the Anatolian plate to the west by major strike-slip faulting on the right-lateral north Anatolian transform fault zone and left-lateral east Anatolian transform fault zone which meet at Karlıova (ELITOK and DONMEZ 2011).

Depending on a N–S compressional tectonic regime, intra-plate deformation is dominant in the eastern Anatolian. Conjugate strike-slip faults of dextral and sinistral character paralleling to North and East Anatolian fault zones are the dominant structural elements of the region. Some of these structures include Ağrı Fault (AF), Bulanık Fault (BF), Çaldıran Fault (ÇF), Ercis Fault (EF), Horasan Fault (HF), Çobandede Fault Zone (ÇFZ), Iğdır Fault (IF), Malazgirt Fault (MF), Balıklıgölü Fault Zone (BFZ), Kağızman Fault Zone (KFZ), Doğubayazıt Fault Zone (DFZ), Karayazı Fault (KYFZ) and Tutak Fault Zone (TFZ), in the studied area shown by rectangular area in Figure 1. Many pull-apart basins have developed along these structures (e.g., Erzurum and Ağrı basins). Although the conjugate strike-slip fault system dominate the active tectonics of eastern Anatolia, the E–W trending basins of compressional origin form the most spectacular structures of the region as they indicate the N–S convergence and shortening of the Anatolian plateau. Muş, Lake Van and Pasinler basins form the best examples of ramp basins in the region (BOZKURT 2001).

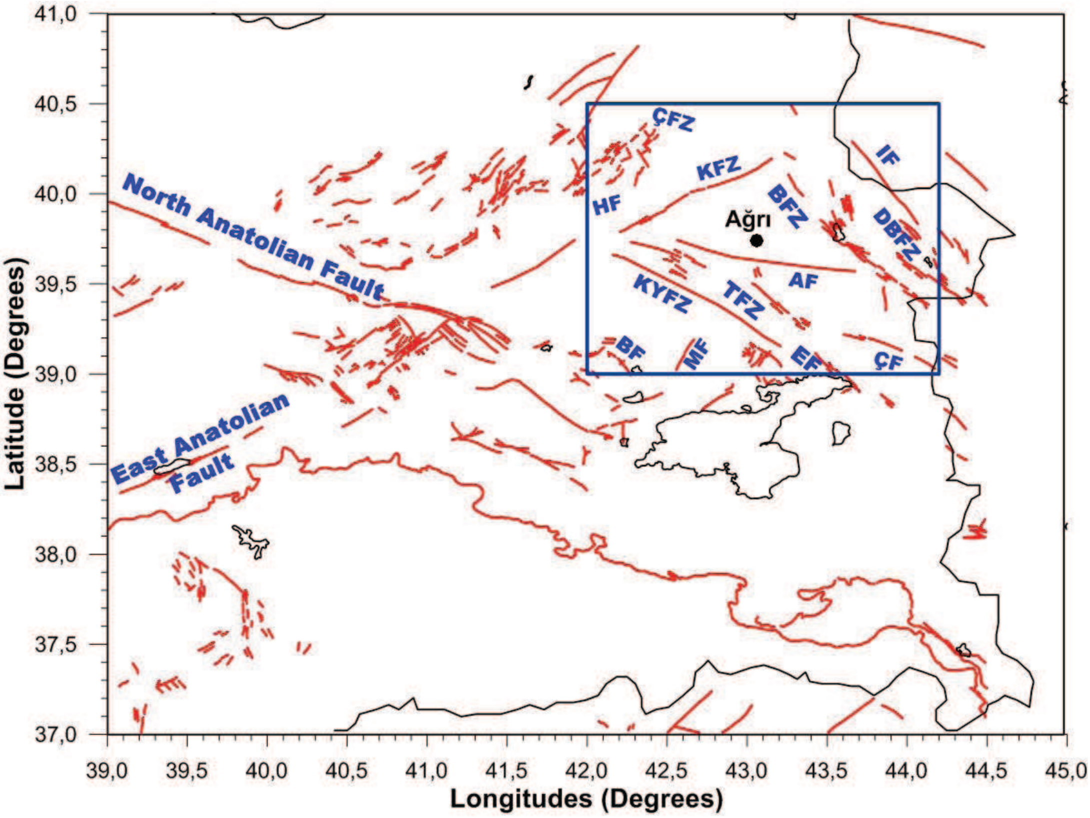

Figure 2. The tectonics in and around Ağrı. The rectangle shows the study area. Ağrı Fault (AF), Bulanık Fault (BF), Çaldıran Fault (ÇF), Ercis Fault (EF), Horasan Fault (HF), Çobandede Fault Zone (ÇFZ), Iğdır Fault (IF), Malazgirt Fault (MF), Balıklıgölü Fault Zone (BFZ), Kağızman Fault Zone (KFZ), Doğubayazıt Fault Zone, Karayazı Fault (KYFZ) and Tutak Fault Zone (TFZ) (BOZKURT, 2001).

The epicenter distribution of earthquakes larger than M=3.0 is shown in Figure 3. The faults in the studied area are seismically active and form the source for many earthquakes. The largest earthquakes, listed in Table 1, occurred in the region are 04 April 1903 Malazgirt (M=6.3), 13 September 1924 Pasinler (M=6.8), 24 November 1976 Çaldıran (M=7.3) and 30 October 1983 Horasan–Narman (M=6.8) (BOZKURT 2001).

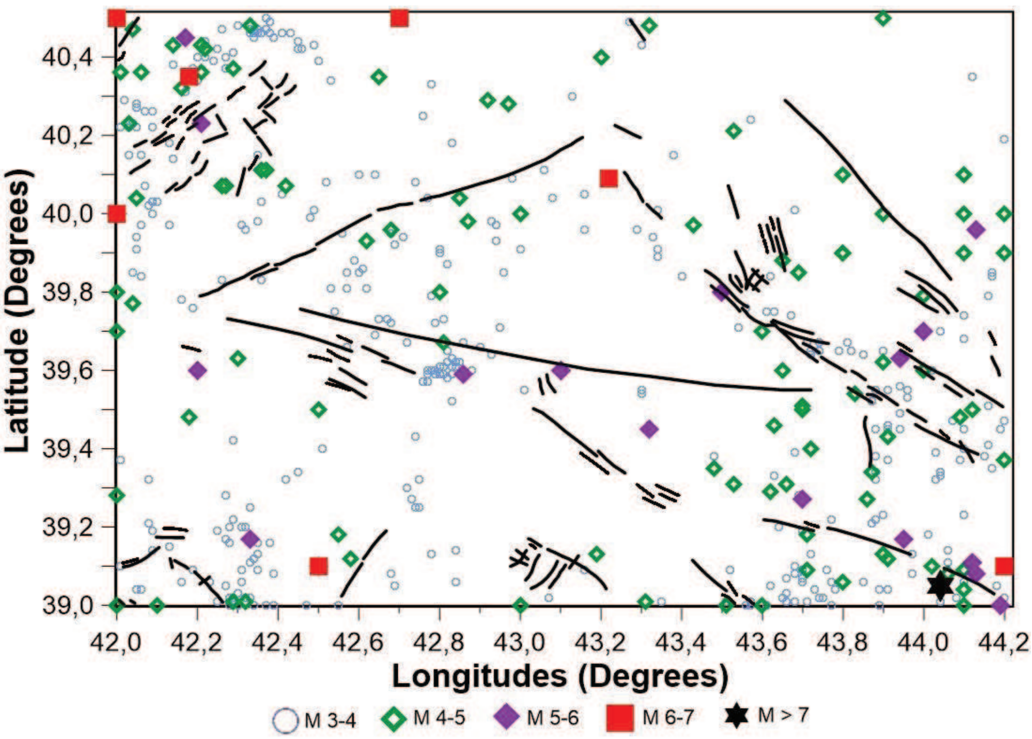

Figure 3. The epicenter distribution of earthquakes occurred in around Ağrı.

Table 1. The large earhquakes occurred in and around Ağrı.

Date	Magnitude (M_S)	Location
28 04 1903	6.30	Malazgirt (42.50ºE, 39.10ºN)
13 09 1924	6.80	Pasinler (42.00ºE, 40.00ºN)
01 05 1935	6.00	Kars-Digor (43.22ºE, 40.09ºN)
15 04 1960	6.00	Horasan-Narman (42.00ºE, 40.50ºN)
24 11 1976	7.30	Çaldıran-Muradiye (44.20ºE, 39.10ºN)
30 10 1983	6.80	Horasan (42.18ºE, 40.35ºN)

4. Methods

The empirical relationship, known as G–R law, between the frequencies of earthquake occurrences and magnitudes can be expressed in the following formula:

$$LogN = a - bM \tag{1}$$

where N is the cumulative number of earthquakes with a magnitude of M and greater, *a* and *b* are constants. *b* is the slope of the frequency–magnitude distribution, and a is the activity level of seismicity. GUTENBERG and RICHTER (1944) firstly estimated the constants known as seismicity parameters. The parameter a exhibits significant variations from region to region as it depends on the level of seismic activity, the period of observation and the length of the considered area as well as the size of earthquakes. 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 conditions over the region. Many factors can cause perturbation of the normal *b* value. On average, the *b* value is near unity for most seismically active regions on the Earth (e.g. FROHLICH and DAVIS 1993). In a tectonically active region, the *b* value is normally close to 1.0 but varies between 0.5 and 1.5 (PACHECO *et al*. 1992; WIEMER and WYSS 1997). However, a detailed mapping of *b* value often reveals significant deviations. The spatial variations of *b* values are related to the distribution of stress and strain (MOGI 1967; SCHOLZ 1968). In addition, some researchers link the *b*-value with the parameters of the rupture process. An example is SCHORLEMMER *et al.* (2005), who showed that the *b*-value is dependent on the faulting style. As pointed out by AMITRINO (2012), in laboratory experiments with brittle rocks, the *b*-value depends on the mechanical loading, which is the type of faulting, the confining pressure, or the roughness of the fault sliding surfaces. These observations agree with the dependence of the *b*-value on friction and/or mean stress. The distinction between these two factors remains difficult because they are correlated, as friction decreases when the confining pressure increases (GOEBEL *et al*. 2012). On the other hand, high *b* values are reported from areas of increased geological complexity (LOPEZ *et al*. 1995), indicating the importance of a multifracture area. Increased material heterogeneity or crack density results in high *b* values (MOGI 1962). Thus, a low *b* value is related to a 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) for various regions of the world. They suggested that *b* values range from 0.45–1.50, while MIYAMURA (1962) found that *b* values change from 0.40–1.80 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 and 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). The *b* value for any region can be computed using several methods such as linear least squares regression or by MLE which is the most robust and widely accepted method in which the *b* value is calculated using the formula (AKI 1965);

$$b = \frac{log_{10}e}{\bar{M} - M_{min}} = \frac{0,4343}{\bar{M} - M_{min}} \tag{2}$$

Where $\bar{M}$ is the average magnitude, and M_{min} is the minimum value of the magnitude presenting the data. In order to evaluate these parameters, we used to ZMAP 6 software package (WIEMER 2001).

The parameter at depends on the seismicity of the area, on the time interval for which we have reported events and also on the surface area S outlined by the epicenters. For seismicity study purposes usually at is expressed in one year by the equation:

$$a_1 = a - \log t \tag{3}$$

where *t* is the whole time period covered by the data set.

The expected time interval for the occurrence of an earthquake with a magnitude greater than or equal to *M* is defined as the mean return periods T_m and is given by:

$$T_m = \frac{10^{bM}}{10^{a_1}} \tag{4}$$

This quantity is adopted as a measurement of seismicity. The most probable maximum magnitude of earthquakes in a time period of *t* years:

$$M_t = \frac{a_1 + \log t}{b} \qquad (5)$$

The probability P_t for an earthquake occurrence with magnitude ≥ M during the time span of *t* years:

$$P_t = 1 - \exp(-10^{a_1 - bM} t) \qquad (6)$$

In this paper, we aimed to make a quantitative appraisal of earthquake hazard parameters in and around Ağrı. Particularly the analysis of the expected time interval for the occurrence of an earthquake, the most probable maximum magnitude of earthquakes in a given time period and the probability of an earthquake occurrence supply information on the earthquake hazard. We used a M_S magnitude scale in these equations since our catalogue is uniform of M_S.

5. Discussion and Conclusions

We used 1569 earthquakes occurred between 1900-2014 years in the region of 42.0-44.2 °E and 39.0-40.5 °N in order to evaluate earthquake hazard parameters in and around Ağrı. For this purpose, *a* and *b* parameters of G-R relationships, return periods, expected maximum magnitudes in the next 100 years and probabilities for the earthquakes for certain magnitude values are computed.

In this study, *b* value is calculated using ZMAP 6 software (WIEMER 2001). In particular, the *b* value was obtained by MLE estimation, using Equation (2). An estimation of standard deviation (δb) in *b* value can be obtained using the equation derived by AKI (1965) and modified by SHI and BOLT (1982):

$$\delta b = 2.3 b^2 \sqrt{\frac{\Sigma (M_i - M)^2}{n(n-1)}} \qquad (7)$$

where, *n* is the sample size.

The cut-off magnitude (M_c) for the studied area shown in Figure 3 was estimated to be equal to 2.7 ± 018 with 90% goodness of fit level (Figure 4). The *a* and *b* values for this sequence shown in Figure 4 were estimated to be equal to 4.73 ± 0.22 and 0.68 ± 0.04, respectively with 90% goodness of fit level. The *b* value is lower than the global mean value of 1.0, which indicates that the data consists of larger earthquakes and high differential crustal stress in the region (WIEMER and KATSUMATA 1999; WIEMER and WYSS 2002).

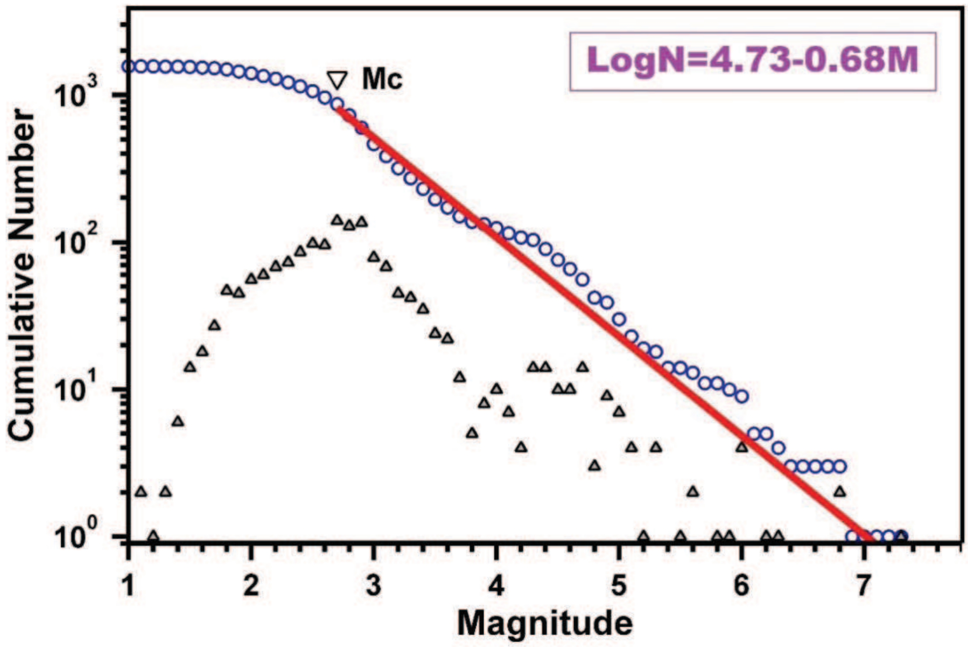

Figure 4. The relationship of Gutenberg- Richter for the earthquakes occurred in around Ağrı.

Spatial mapping of *b* values provides detailed information about seismotectonic situation in the studied area. For this purpose, data are projected onto a plane to visualize values of *b* as a function of space. The mapping of *b* values is performed in a 0.1° × 0.1° grid, selecting the nearest 50 events in each node and 25 events of the minimum number. The estimated *b* value varies from 0.4 to 1.55 as seen from Figure 5. The *b* values lower than 0.8 are related to the area with high-stress regions including IF, DBFZ, BFZ, ÇF, EF and HF. *b* values between 0.8 and 1.0 are found in the region covering TF and KYFZ. It is observed *b* values larger than 1.0 in the west, northwest and southwest of Ağrı. It reveals that this region is associated with highly heterogeneous and fractured rock matrix that may be associated with fluids or viscous materials with fluids into the fractured rock matrix (SINGH *et al*. 2012a, b). The regions in the east and southeast of Ağrı, east of Horasan and around Patnos are related to *b* values lower than 0.8. It can be concluded that these regions have high stress levels and capacity to occur large earthquakes in the future time.

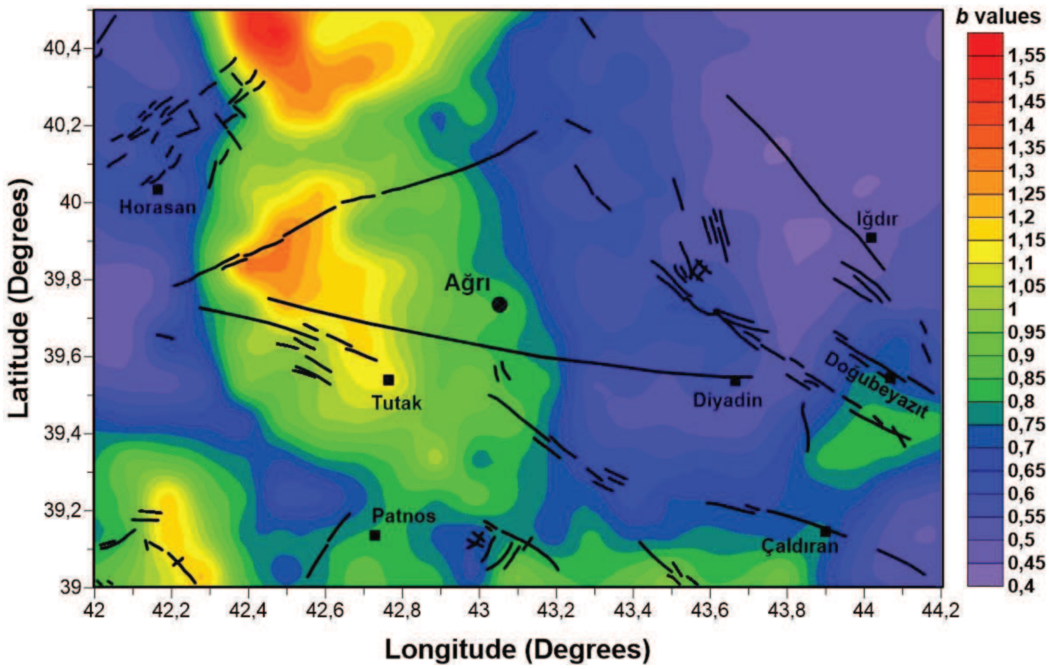

Figure 5. The spatial distribution of b values computed from Gutenberg-Richter relationships for the earthquakes occurred in around Ağrı.

Spatial mapping of M_{100} values which computed by Equation 5 is shown in Figure 6. M_{100} is the most probable maximum magnitude of earthquakes in a time period of next 100 years. The mapping of M_{100} values is performed in a $0.1° \times 0.1°$ grid interval. The computed values change between 3.6 and 7.0 as shown in Figure 6. The values larger than 6.0 are computed in the IF, DBFZ, ÇF, HF and ÇFZ which produce large earthquakes as shown in Figure 2. The earthquake hazard level in the regions of Doğubeyazıt-Iğdır, Horasan-Pasinler and Çaldıran-Muradiye is very high and there is a probability to occur an earthquake larger than 6.0 in this region in the next 100 years. The magnitudes of expected earthquakes in the region between Ağrı and Horasan are lower than 5.0. The results show that there is an earthquake hazard about 5.5 around Patnos. The results show that the earthquakes larger than 5.5 may be occurred in the regions of the east and southeast of Ağrı, Horasan-Pasinler and around Patnos where *b* values lower than 0.8 have been observed (Figure 5), It can be concluded that these regions have high stress levels and capacity to occur large earthquakes in the next 100 years.

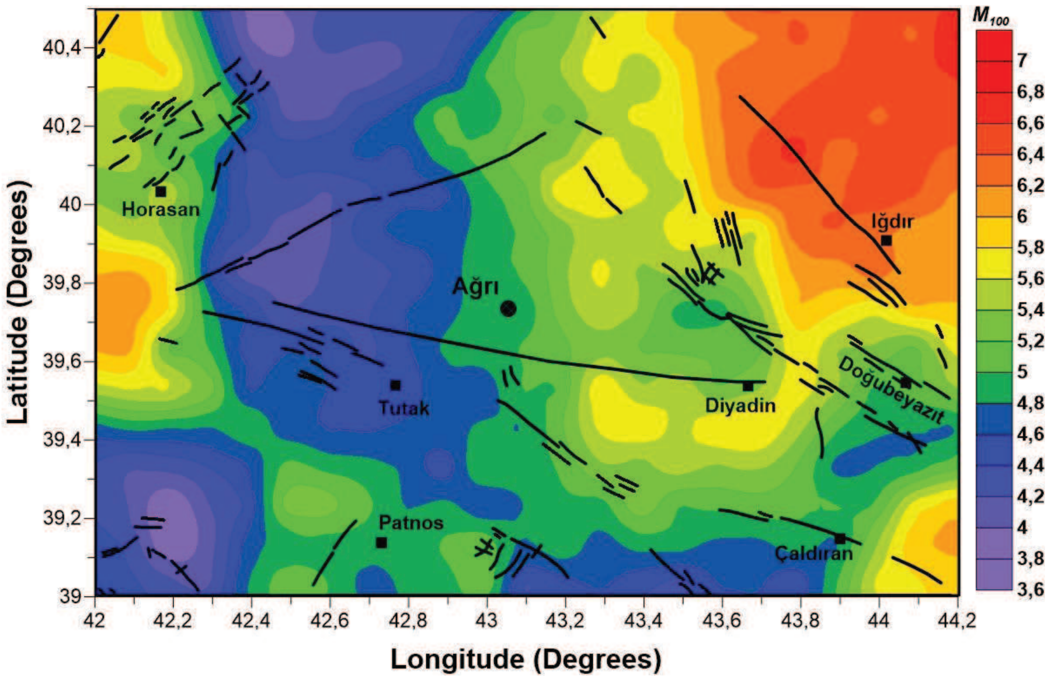

Figure 6. The spatial distribution of M_{100} values (expected maximum earthquake in the next 100 years) computed from Gutenberg-Richter relationships for the earthquakes occurred in around Ağrı.

Earthquake recurrence times (return periods, T_m) computed from equation 4 and the probability of occurrence computed from equation 6 using the parameters of G-R relationship for the earthquakes larger a certain magnitude value during a given time span are listed in Table 2. Also, earthquake hazard curves expressed in terms of the return period and probabilities of earthquakes are shown in Figures 7 and 8. The mean return periods estimated for the studied area change between 5 and 176 years for magnitudes of 5.0-7.3 as listed in Table 2 and shown in Figure 7. For example, an earthquake equal to 6.0 which could cause damage to buildings and lost human may be occurred every 23 years. This is very high seismic risk value and we can conclude that the studied area very dangerous. Earthquake hazard curves expressed by the probability expected for earthquakes with the maximum observed magnitudes and plotted for magnitudes (and during the time span of 25, 50 and 100) are shown in Figure 8. The probabilities of an earthquake with M=6.0, 6.5 and 7.0 in the next 100 years are 99%, 86% and 59%, respectively. The magnitude of the largest earthquake occurred in the studied area is equal to 7.3 and the probability of it in the next 100 years is 43%.

Table 2. The large earhquake risk values for next 25, 50 and 100 years.

M_s	***Earthquake Risk (%)***			***Return Period(T_m)***
	Years			
	25	***50***	***100***	
5.0	0.99	1.00	1.00	5
5.1	0.99	1.00	1.00	6
5.2	0.98	1.00	1.00	7
5.3	0.96	1.00	1.00	8
5.4	0.93	1.00	1.00	9
5.5	0.9	0.99	1.00	11
5.6	0.86	0.98	1.00	13
5.7	0.82	0.97	1.00	15
5.8	0.77	0.95	1.00	17
5.9	0.71	0.92	0.99	20
6.0	0.66	0.88	0.99	23
6.1	0.6	0.84	0.97	27
6.2	0.54	0.79	0.96	32
6.3	0.49	0.74	0.93	37
6.4	0.44	0.68	0.9	44
6.5	0.39	0.63	0.86	51
6.6	0.34	0.57	0.81	59
6.7	0.3	0.51	0.76	69
6.8	0.27	0.46	0.71	81
6.9	0.23	0.41	0.65	95
7.0	0.2	0.36	0.59	111
7.1	0.18	0.32	0.54	129
7.2	0.15	0.28	0.48	151
7.3	0.13	0.25	0.43	176

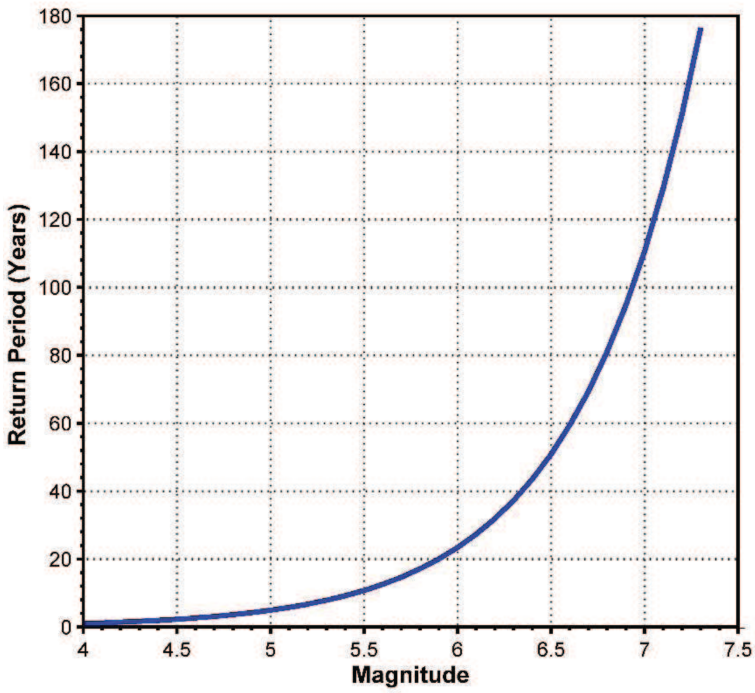

Figure 7. The return periods of earthquakes in around Ağrı.

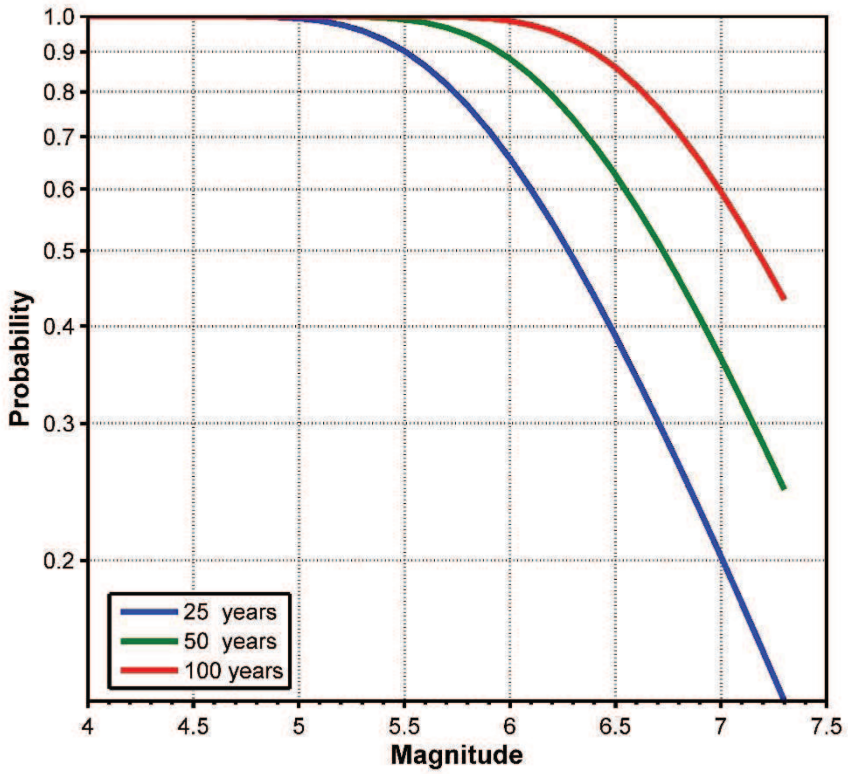

Figure 8. The probabilities for earthquakes for next 25, 50 and 100 years in around Ağrı.

There is not any risk to occur earthquake larger than 5.0 in the center of Ağrı according to spatial distribution of *b* and M_{100} shown in Figures 6 and 7 in the next 100 years. But, Ağrı is surrounded by active faults and probability of earthquakes greater than 6.0 in these faults is very high. There is a liquefaction risk in Ağrı due to a young sediment basin and alluvial layer is tick. We can concluded that there is very high hazard on the buildings and human's life considering liquefaction associated with an earthquake might occur and this alluvium layer grows up to ten times the earthquake waves (SEMBLAT *et al*. 2005).

6. Results

The earthquake hazard parameters in and around Ağrı was evaluated for time interval of 1900-2014 years. For this purpose, *a* and *b* parameters of G-R relationships, return periods, expected maximum magnitudes in the next 100 years and probabilities for the earthquakes for certain magnitude values are computed. *a* and *b* values for this time period were estimated to be equal to 4.73 and 0.68, respectively. This *b* value shows that that the data consists of larger earthquakes and high differential crustal stress in the region. The regions in the east and southeast of Ağrı, east of Horasan and around Patnos have high stress levels and capacity to occur large earthquakes in the future time according to the mapping of *b* values. It is found that earthquakes larger than 5.5 may be occurred in the regions where *b* values lower than 0.8 have been observed in the next 100 years. The return periods in the studied area are estimated between 5 and 176 years for magnitudes of 5.0-7.3. The probabilities of an earthquake with M=6.0, 6.5 and 7.0 in the next 100 years are computed 99%, 86% and 59%, respectively. The probability of the largest earthquake occurred in the studied area is 43% in the next 100 years. The faults around Ağrı are seismically active and have potential to an earthquake larger than 6.0. Since the sediment basin of Ağrı is very young and alluvial layer is tick, there is very high hazard on the buildings and human's life in Ağrı.

Acknowledgements: The authors would like to express their sincere thanks to Prof. Dr. Ali Pınar and the reviewers for the suggestions made in order for the paper to be improved. Also, the authors are grateful to Ağrı İbrahim Çeçen University BAP (Turkey) for partially supporting this work (with project number: PDBMF.15.001).

REFERENCES

AKI, K. (1965), *Maximum likelihood estimate of b in the formula log N = a - bM and its confidence limits*. Tokyo Univ. Bull. Earthq. Res. Inst. *43*, 237–239.

AMITRANO, D. (2012), *Variability in the power-law distribution of rupture events. How and why does b-value change?* European Physical Journal Special Topics. *205*, 199-215.

ASLAN, E. (1972), *Magnitude and time distributions of earthquakes in Turkey*. Bull Int Inst Seismol Earthq Eng. *7*, 1–10.

BATH, M. (1979), *Seismic risk in Turkey—a preliminary approach*. Tectonophysics. *54*, 9–16.

BAYRAK,Y., YILMAZTURK, A., and OZTURK, S. (2005), *Relationships between fundamental seismic hazard parameters for the different source regions in Turkey.* Nat Hazards. *36*, 445–462.

BAYRAK, Y., OZTURK, S., CINAR, H., KALAFAT, D., TSAPANOS, T. M., KORAVOS, C.G., and LEVENTAKIS, G.A. (2009), *Estimating earthquake hazard parameters from instrumental data for different regions in and around Turkey.* Eng Geol. *105*, 200–210.

BAYRAK, Y., OZTURK, S., and ERDURAN, A., (2002), *The relationships between maximum magnitudes and modal values for different regions of Turkey*. 3rd balkan geophysical congress and exibition. 8–4, 24–28 June, Sofia, Bulgaria.

BAYRAK, E., YILMAZ, Ş., SOFTA, M., TURKER, T., and BAYRAK, Y. (2015), *Earthquake hazard analysis for East Anatolian Fault Zone, Turkey,* Nat. Hazards. *76*, 1063-1077.

BOZKURT, E. (2001), *Neotectonics of Turkey – a synthesis*. Geodinamica Acta. *14*, 3-30.

ELITOK, O. and DOLMAZ, M.N. (2011), *Tectonic Escape Mechanism in the Crustal Evolution of Eastern Anatolian Region (Turkey)*, New Frontiers in Tectonic Research - At the Midst of Plate Convergence, Dr. Uri Schattner (Ed.), ISBN: 978-953-307-594-5, InTech, Available from: http://www.intechopen.com/books/newfrontiers-in-tectonic-research-at-the-midst-of-plate-convergence/tectonic-escape-mechanism-in-the-crustalevolution-of-eastern-anatolian-region-turkey

ERDIK, M., ALPAY, B. Y., ONUR, T., SESETYAN, K., and BIRGOREN, G. (1999), *Assesment of earthquake hazard in Turkey and neighboring regions*. Ann Geophys. *42*, 1125–1138.

FROHLICH, C., and DAVIS, S.C. (1993), *Teleseismic b values; or, much ado about 1.0*. J Geophys Res. *98*, 631–644.

GUTENBERG, R., RICHTER, C.F. (1944), *Earthquake magnitude, intensity, energy and acceleration*, Bull Seismol Soc Am. *32*, 163–191.

GOEBEL, T.H.W., SCHORLEMMER, D., DRESEN, G., and BECKER, T.W. (2012), *Stress-driven in bv alues during stick-slip on laboratoty fracture granite surfaces*. Journal of Geophysical Research. Doi:10.1029

KAYABALI, K., AKIN, M. (2003), *Seismic hazard map of Turkey using the deterministic approach*. Eng GeoL. *69*,127–137.

LOPEZ, C.C., SANZ DE GALDANO, C., DELGADO, J., and PEINADO, M.A. (1995), *The b parameter in the Betic Cordillera, Rif and nearby sectors. Relations with the Tectonics of the region*. Tectonophysics. *248*, 277–292.

MANAKOU, M.V., and TSAPANOS, T.M. (2000), *Seismicity and seismic hazard parameters evaluation in the island of Crete and the surrounding area inferred from mixed files*. Tectonophysics. *321*, 157–178.

MIYAMURA, S. (1962), *Magnitude–frequency relations and its bearing on geotectonics*. Proc Jpn Acad. *38*, 27–30.

MOGI, K. (1962), *Magnitude–frequency relationship for elastic shocks accompanying fractures of various materials and some related problems in earthquakes*. Bull Earthq Res Inst Univ Tokyo. *40*, 831–883.

MOGI, K. (1967), *Earthquakes and fractures,* Tectonophysics. *5*, 35–55.

MCNALLY, K.C. (1989), *Earthquakes and seismicity. In: James DE (ed) The encyclopedia of solid earth geophysics*. Springer, 308–315.

PACHECO, J., SCHOLZ, C., and SYKES, L. (1992), *Changes in frequency–size relationship from small to large earthquakes*. Nature. *355*, 71–73.

SCHOLZ, C.H. (1968), *The Frequency–magnitude relation of microfracturing in rock and its relation to earthquakes,* Bull Seismol Soc Am. *58*, 399–415.

SCHORLEMMER, D., WIEMER, S., and WYSS, M. (2005), *Variations in earthquake size distribution across different stress regimes,* Nature. *437*, 539–542.

SEMBLAT, J.F, KAHAM, M., PARARA, E., BARD, P.Y., PITILAKIS, K., MAKRA, K. and RAPTAKIS, D. (2005), *Seismic wave ampications: Basin Geometry vs soil layering*, Soil Dynamics and Earthquake Engineering. *25* (7-10), 529-538.

SHI, Y., and BOLT, B.A. (1982), *The standard error of the magnitude-frequency b-value,* Bull. Seismol. Soc. Am. *72*, 1677 – 1687.

SINGH, A.P., MISHRA, O.P., YADAV, R.B.S., and KUMAR, D. (2012a), *A new insight into crustal heterogeneity beneath the 2001 Bhuj earthquake region of northwest India and its implications for rupture initiations*, Journal of Asian Earth Sciences. *45*, 31–42.

SINGH, A.P., MISHRA, O.P, KUMAR, D., KUMAR, S., and YADAV, R.B.S. (2012b), *Spatial variation of the aftershock activity across the Kachchh Rift Basin and its seismotectonic implications*, Journal of Earth System Sciences. *121* (2), 439–451.

UDIAS, A., and MEZCUA, J. (1997), *Fundamentos de Geofisica, QE 501*. Alianza Editorial, Madrid.

WIEMER, S., and WYSS, M. (1997), *Mapping the frequency–magnitude distribution in asperities: an improved technique to calculate recurrence times,* J. Geophys Res. *102*, 15115–15128.

WIEMER, S., and KATSUMATA, K. (1999), *Spatial variability of seismicity parameters in aftershock zones*. J. Geophys. Res. *13*, 135-151.

WIEMER, S. (2001), *A software package to analyze seismicity: ZMAP.* Seismol Res Lett. *72*, 373–382.

WIEMER, S., and WYSS, M. (2002), *Mapping spatial variability of the frequencymagnitude distribution of earthquakes,* Adv. Geophys. *45*, 259–302.

YARAR, R., ERGUNAY, O., ERDIK, M., and GULKAN, P. (1980), *A preliminary probabilistic assessment of the seismic hazard in Turkey.* In: Proceedings of the 7th World conference on earthquake Engineering, Istanbul. 309–316.