A Homogeneous Earthquake Catalogue for Turkey

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Abstract. A new homogenised earthquake catalogue for Turkey is compiled for the period 1900 – 2018. The earthquake parameters are obtained from the Bulletin of International Seismological Centre that is fully updated in 2020. New conversion equations between moment magnitude and the other scales (m_d, M_L, m_b, M_s and M) are determined using the General Orthogonal Regression method to build up a homogeneous catalogue, which is the essential database for seismic hazard studies. The 95% confidence intervals are estimated using the bootstrap method with 1000 samples. The equivalent moment magnitudes (M_w*) for the entire catalogue are calculated using the magnitude relations to homogenise the catalogue. The magnitude of completeness is 2.7 M_w*. The final dataset is not declustered or truncated using a threshold magnitude because of a widely usable catalogue. It contains not only M_w*, but also the average and median of the observed magnitudes for each event. Contrary to the limited earthquake parameters in the previous catalogues for Turkey, the 45 parameters of ~409k events are presented in this study.

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1 Introduction

The earthquake catalogues are the first output of seismological observations. Several institutions around the world generate national and international catalogues for understanding the seismic activity of a region. Principally, a catalogue contains the parameters such as origin time, coordinates and focal depth. Earthquake magnitude is another vital parameter which is a dimensionless scale of releasing energy. Magnitude is defined with different scales (types) based on different seismic wave phases and calculation approximations (Table 1). A catalogue may not contain all magnitude scales for an event. If an earthquake catalogue is used to show seismicity on a map, the magnitude type may not be important because the differences among the values of scales are not too large for visualisation. However, magnitude scale information used in energy calculation is crucial for seismic hazard studies.

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There are several unknowns in magnitude calculations by institutions due to the equations coefficients, seismic network structures, human-made mistakes etc. Both amplitude and distance coefficients in the magnitude equations are the major items. Although the coefficients must be specific for a region because of seismic wave attenuation in the crust and mantle, the calculated values for the Californian earthquakes (i.e. for local magnitude by Richter, 1935; Hutton and Boore, 1987) are

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widely used. On the other hand, magnitudes, except m_d, are calculated using the waveform amplitudes at each station for an event. Different amplitudes are observed for an event because of the source radiation pattern. Generally, the average magnitude for all stations is calculated to minimize the effect of the radiation pattern. The median is also preferred to exclude the magnitude outliers (Havskov and Ottemöller, 2010). Consequently, the average magnitude is closely related to several factors such as the number of stations, the standard deviation of the average, amplification or attenuation due to the geological structure beneath the station, and the radiation pattern that is related to the azimuthal distribution of stations. Therefore, institutions may report different magnitudes for an event.

Another issue picked out in this study is the reported moment magnitudes (M_w) in the catalogues. M_w is determined using waveform modelling for events ($M_w \geq$ 3.5-4.0) with a high signal-to-noise ratio. However, a few institutes report M_w for small events to the international catalogues (M_w<3.0, i.e. 25.01.1999 13:06 M_w=1.8 by Cyprus Geological Survey Department; 29.05.2014 01:14 M_w=1.8 by the Earthquake Research Center, Ataturk University). These small moment magnitudes are obviously determined by using an empirical relationship without using waveform data. As a result, there are more than one reported magnitude values for an event with known and unknown calculation errors. One common magnitude scale should be used to standardise analyses in the studies based on the parametric data such as hazard mitigation. Therefore, a homogenized catalogue with a unified magnitude scale becomes essential. In the last two decades, the studies on unifying earthquake magnitudes and generating improved catalogues are carried out for different regions on the Earth (i.e. Grünthal et al., 2009; Chang et al., 2016; Manchuel et al., 2018; Rovida et al., 2020).

Table 1. Symbols for different magnitude scales in the priority order of magnitude saturation.

M_w	Moment magnitude
M_s	Surface wave magnitude
m_b	Body wave magnitude
M_L	Local (Richter) magnitude
m_d	Duration magnitude
M	General magnitude (unreported type)

This study focuses on earthquakes in Turkey. The region is one of the most geodynamically active areas because of the deformation among the Eurasian, African and Arabian plates (Fig. 1). Both the Arabia-Eurasia continental collision and the subduction of the African Plate beneath Eurasia started in the Early/Middle Miocene (11-23 Ma). The interactions of the three plates are the major driving forces for the tectonics of the region. The plate motions result in thrust faulting in Eastern Anatolia, Caucasus and Iran, normal faulting in Western Turkey and Greece, transform faults due to escaping to the west and east (see Bozkurt, 2001 for a brief synthesis). The complexity of the Eastern Mediterranean tectonics causes a high earthquake activity with different faulting mechanism and a wide range of focal depths. The western Anatolia is the most

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seismically active part of Turkey. Both N-S extension in Aegean and the westward motion of Anatolian Plate along the NAFZ cause a dense deformation with small to moderate earthquakes in western Turkey. The North and East Anatolian Fault zones are also the primary seismic sources that generate destructive earthquakes (Mw ≥ 6).

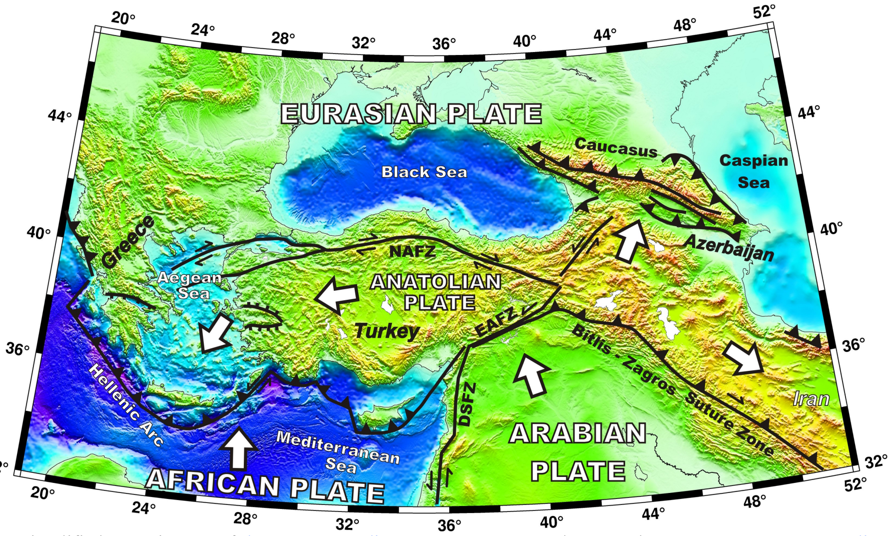

Figure 1. Simplified tectonic map of the Eastern Mediterranean. DSFZ: Dead Sea Fault Zone, EAFZ: East Anatolian Fault Zone, NAFZ: North Anatolian Fault Zone. Triangles indicate the direction of vergence or subduction. Bars are the down-thrown side of normal faults. White arrows are relative plate motions. The relief model is generated with the ETOPO1 model (Amante and Eakins, 2009).

The destructive earthquakes in Turkey and the surrounding countries along the centuries are found in the historical records. Pınar and Lahn (1952), Ergin et al. (1967, 1971), Soysal et al. (1981), Güçlü et al. (1986), Ambraseys and Finkel (1995), and Ambraseys and Jackson (1998) compile the historical earthquakes in the region. Tan et al. (2008) present the historical events on a digital database and the first focal mechanism catalogue of Turkish earthquakes. On the other hand, Leptokaropoulos et al. (2013) and Kadirlioğlu et al. (2018) introduce homogenised catalogues. The main component of homogenisation is to obtain reliable magnitude conversion from one scale to moment magnitude. Several empirical relations are also proposed for the region (Papazachos et al., 1997; Ambraseys 2000; Baba et al., 2000; Papazachos and Papazachou, 2003; Burton et al., 2004; Ulusay et al., 2004; Scordilis, 2006; Akkar et al., 2010; Deniz and Yücemen, 2010; Makropoulos et al., 2012).

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The motivation of this study is to build a widely usable earthquake catalogue (i.e. for geophysicists, geologists, earthquake engineers) that contains homogenised moment magnitudes and the other seismological parameters. During the international seismic hazard studies of the Sinop Nuclear Power Plant planned in northernmost of Turkey, it is clearly understood that a comprehensive homogenised earthquake catalogue for Turkey is needed for future studies. For this aim, the earthquakes in Turkey are statistically analysed and the empirical magnitude relation equations are obtained using a refined data set. Then, an extensive homogenised earthquake catalogue is constructed. The distinguishing feature of the new homogenised catalogue is that it contains all earthquakes in a manageable format without removing aftershocks and truncating small events.

2. Database and processing

The Bulletin of the International Seismological Centre (ISC, 2020) is used as the main database to generate a new and comprehensive homogeneous earthquake catalogue for Turkey. The ISC Bulletin contains a large number of parametric data for an event that occurred anywhere on the Earth. Because national and international seismological centres contribute to the bulletin, it contains not only moderate-to-large events (M≥4) but also local earthquakes with small magnitudes (M<4). The most important feature of the bulletin is that an event with sufficient data is manually checked and relocated by a seismologist. Therefore, the latest earthquake information in the database is two years behind in real-time (ISC, 2020). The bulletin also presents the event parameters reported by the contributor centres. The ISC finished rebuilding the entire database in 2020 by utilizing a new location algorithm (Bondár and Storchak, 2011) with the *ak135* seismic velocity model (Kennett et al., 1995). Furthermore, previously unavailable hypocentre and station phase readings from the permanent and temporary networks are added to the rebuild bulletin (ISC, 2020; Storchac et al., 2017). Therefore, the latest and revised international dataset is used in this study.

The earthquake parameters in the bulletin are in the IASPEI Seismic Format (ISF, 2020). Each event has its own data block that contains several data types and comments such as origin and magnitude. Data and comment lines have no specific flag to identify their types, and it is not possible to read the database using a simple computer program or shell-scripts. A Fortran code is written to analyse the ISF lines using the parsing subroutines provided by the ISC. The different parsers check each line in the database to identify the data type. After determining the origin and magnitude sub-blocks of an event properly, the parameters are analysed. The overall data processing is given in the flowchart in Fig. 2. Because the bulletin may contain the multiple hypocentres from multiple agencies for an event, the ISC considers that one of them is primary and assigns the *PRIME* flag to it. A hypocentre determined by the ISC always has the *PRIME* flag. In this study, the event origin parameters such as time, location, and focal depth with the PRIME flag are searched in the first step. If there is no *PRIME* flag, the origin data is searched in the secondary hypocentres using the institute priority order given in the flowchart. The parameters reported by the ISC are preferred first. If there is no information from the ISC, the availability of the hypocenter parameters

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from the European-Mediterranean Seismological Centre (CSEM or EMSC) is searched (see Appendix A for the institute abbreviations). The priority of both institutes is high because they use all available data in the study area. In turn, the hypocentre parameters of the two Turkish seismological networks are searched (ISK: Kandilli Observatory and Earthquake Research Institute, KOERI; DDA: General Directorate of Disaster Affairs until September 2017; Disaster and Emergency Management Presidency - AFAD after October 2017). The local institutes are preferred for the events that occurred in the neighbouring countries. Besides, the earthquake information reported by ISS and GUTE is used for the period of 1900-1964. If the event origin parameters are found in any step of the query order, this event is added to the homogenised catalogue with these parameters.

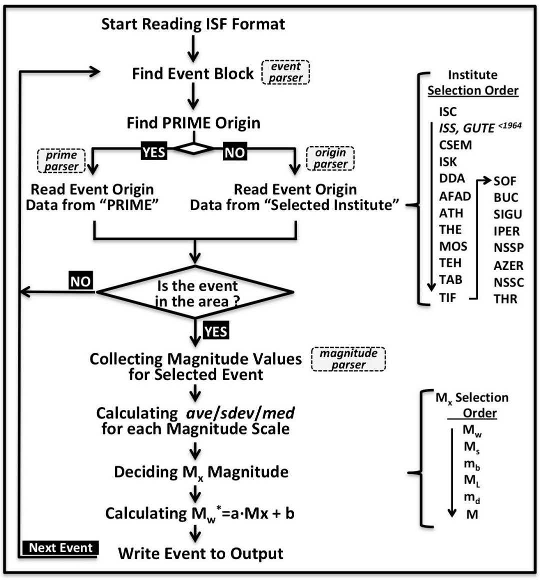

Figure 2. Flowchart of the ISC database processing. Ave: Average (mean), Med: Median, Sdev: Standard deviation. Mw* is equivalent moment magnitude. See Appendix A for the institute codes.

After determining the event origin parameters in the selected area, the magnitude data sub-block is analysed by the magnitude parser. The reported values of different magnitude scales given in Table 1 are collected. If there are two or more values for a magnitude scale, the arithmetic mean and median of all reported values are calculated. Selecting a magnitude value from a particular institute such as KOERI, Harvard, and EMSC is not preferred to overcome the problems such as unreported magnitude, the effect of network distribution, and calculation errors.

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More than 8.3 million events in the ISC monthly data sets are analysed for the final catalogue. The study area is bounded by 34°N - 44°N and 24°E – 46°E (Fig. 3). The final catalogue contains 408,823 events occurred in the period from 1900 to October 2018. The modern instrumental period (1964-present) data is used for all statistical analyses. The number of events (1964-2018) reported with local magnitude (M_L) is 253,153 (62% of the total), and it is the highest rate concerning the other magnitudes types (Fig. 4). About 39% of the events have duration magnitudes (m_d). Because both magnitudes types are widely determined by the national institutions, especially for the local events, they are dominant in the catalogue. The body (m_b) and surface wave (M_s) magnitudes are reported for only 3.9% and 1.6% of the total events in the region, respectively. Though moment magnitude (M_w) is the most preferred magnitude scale for seismic hazard studies, only 1.0% of all events have M_w because waveform analyses are not easy and routine process. On the other hand, the final catalogue contains 19,498 (4.8%) events with no specified magnitude types (M). The magnitude M is mostly reported until 1990, and the number of events with M dramatically decreases after this year. Approximately 2% of the annual activity is reported without a magnitude value in the study area. These events are excluded from the final homogenised catalogue.

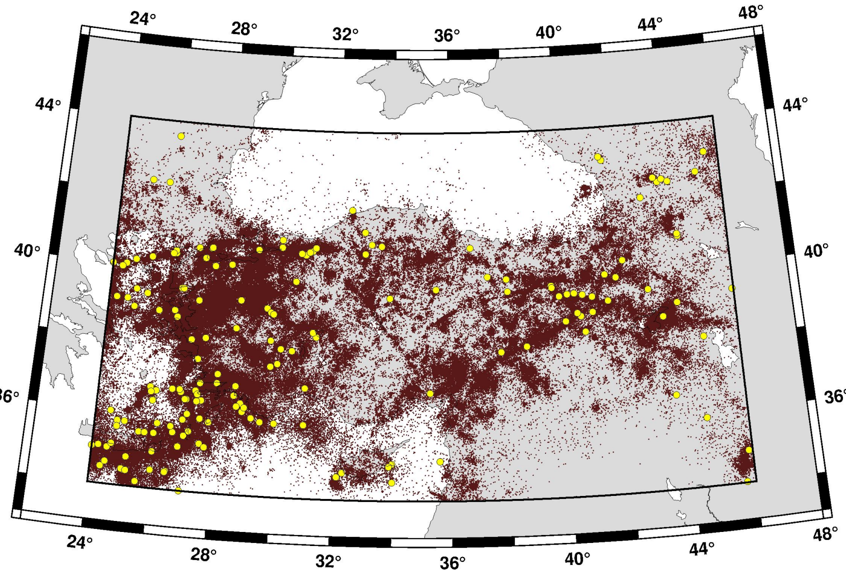

Figure 3. The earthquakes in the homogenised catalogue (dots). Yellow circles are the events with an equivalent moment magnitude (Mw*) greater than 6.0 (total 179 events).

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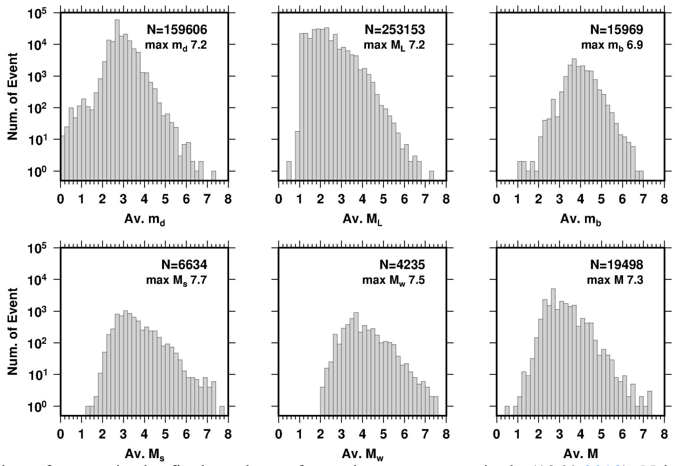

Figure 4. The number of events in the final catalogue for each average magnitude (1964-2018). N is the total number of event for each magnitude.

Table 2. Top: Number of magnitudes with zero and non-zero values between 1964 and 2018 in the catalogue. Bottom: The number of magnitude pairs with non-zero values.

	m_d	M_L	m_b	M_s	M_w	M
=0	248,933	155,386	392,570	401,905	404,304	389,041
≠0	159,606	253,153	15,969	6,634	4,235	19,498

	m_d , M_w	M_L , M_w	m_b , M_w	M_s , M_w	M , M_w
≠0	1,990	3,702	2,740	2,150	98

3. Catalogue homogenization and completeness

3.1 Refining the dataset

The dataset is refined in detail for regression analyses to obtain the empirical relations between the magnitude scales. In the first step, the catalogue is declustered using Reasenberg's (1985) second-order moment approximation because removing aftershocks is necessary to determine reliable magnitude completeness. For aftershock analysis in space, a subsequent event is searched in an area with a radius of 20 times of the circular source dimension of the preceding event considering ±4 km hypocentre uncertainties (Kanamori and Anderson, 1975; Reasenberg, 1985). The maximum interaction period for the next event in a sequence is ten days to build a temporal cluster extension. After declustering, the earthquakes that occurred after

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1980 are selected for the subsequent analyses because the Turkish national station networks and data processing become much more reliable (i.e. Mignan and Chouliaras, 2014; Canbaz et al., 2019). In the third step, completeness (Mc) for each magnitude is determined. It is found that Mc is ~2.8 for m_d and M_L whereas ~4.0 for m_b and M_s. The events with an average magnitude smaller than the Mc-thresholds of each magnitude scale are excluded from the regression. Using a threshold also helps eliminate possible blasts (M < 2.0-2.5) before the regression. In the last step, a cut-off value is applied for high differences between magnitude pairs. There are, naturally, differences among the reported magnitudes for an earthquake. Occasionally, the difference between the magnitude pairs may be as large as two or more magnitude units. After obtaining the difference scattering for each pair, the data points that are out of the 95% confidence interval (±2σ) are removed by using the Interquartile Range (IQR) method (Galton, 1869; MacAlister, 1879). The IQR is one of the robust methods for outliers and can be successfully applied to seismological data (i.e. Tan et al., 2010, 2014; Tan, 2013). The cut-off values are determined as 0.85 (m_d-M_w), 0.67 (M_L-M_w), 0.55 (m_b-M_w), 1.1 (M_s-M_w), and 1.0 (M-M_w). These cut-offs overcome the scattering of the pairs. After refining the magnitude pairs in the four steps, the number of data used in regression is 1484, 2199, 940, 470 and 55 for m_d-M_w, M_L-M_w, m_b-M_w, M_s-M_w and M-M_w, respectively (Fig. 5).

3.2 Regression Analyses

The relationships of the refined magnitude pairs are estimated using the general orthogonal regression (GOR). The method is a better estimator than the least-square (LS) approximation when both *x* and *y* variables have non-negligible size errors (Castellaro et al., 2006). The slope (*a*) and intercept (*b*) value of the GOR line in the form of $y = a \cdot x + b$ is given by

$$a = \frac{S_Y^2 - \eta S_X^2 + \sqrt{(S_Y^2 - \eta S_X^2) + 4\eta S_{XY}^2}}{2S_{XY}} \quad (1)$$

$$b = \bar{Y} - a\bar{X} \quad (2)$$

where S_X^2, S_Y^2 and S_{XY}^2 are the covariance of *X* (independent variable), *Y* (dependent variable) and between *X* and *Y*, respectively (i.e. Castellaro et al., 2006; Das et al., 2014). $\bar{X}$ and $\bar{Y}$ are the average values of the variables. η is the error variance ratio of the variables ($\sigma\varepsilon_X$, $\sigma\varepsilon_Y$) and defined as $\eta = (\sigma\varepsilon_X / \sigma\varepsilon_Y)^2$. When the standard errors of the variables are not known, η is arbitrary set to a value. In practice, $\eta = 1$ (squared Euclidean distance) gives good results (Castellaro et al., 2006; Das et al., 2014). In this study, η is tested for the values from 0.5 to 2.0 to seek a better fit. The R^2 values do not increase when η is assigned different than 1.0, and a significant improvement is not observed in the regressions. Besides, the real errors of the magnitudes are not known; $\eta = 1$ is used. The squared Euclidean distance gives better results for all magnitude scales. The 95% confidence intervals of the best-fit regression are determined with the bootstrap method (Efron, 1979). Total 1,000 new regressions are calculated using 50% of the total number of data of each relation. The bootstrap samples are randomly selected using the Mersenne Twister random number generator (Matsumoto and Nishimura, 1998).

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The random numbers are unique in each test to prevent multiple selections of any datum. After obtaining a large set for the constants *a* and *b* of the linear fits, the outliers are removed with the IQR method. Then, the standard deviation (σ) of the normally distributed dataset is calculated.

The GOR results are given in Table 3 and Fig. 5. Because the number of magnitude pairs is high for each relation, the data is shown with coloured density contours in 0.1 magnitude-unit grids. It is clear that all relations are linear, and that the minimum misfit regression lines are in good agreement with the data distribution. The number of pairs is generally dense between magnitude values of 3.0 and 5.0 and decrease for larger magnitudes. In general, the slopes of the regression lines are close to 1, and the intercept values are negative, except for M_s magnitude. The relation between m_d and M_w indicates that both magnitude scales are equal at m_d = 4, and the difference increases up to 0.4 magnitude unit at larger values. M_L values are dense between 3 and 5, and the linear fitting line extends close to the y=x line. The difference between local and moment magnitudes is about 0.25 at M_L = 7.0. The conversion equation of m_d-M_w is similar to that of M_L-M_w. The most considerable difference between the two different magnitude scales is observed for surface and moment magnitudes. M_s is always smaller than M_w, and the difference is about 0.6 at M_s = 4.0. Both scales are equal at M_s = 7.5. The magnitude M (the real type is not known) is mostly reported in the past. There are 26 events only with M ≥ 5.0 before 1964 in the study area. Therefore, an M-M_w conversion is necessary for seismic hazard analyses using long-term seismicity data. There are few magnitude pairs (N = 55), and they are distributed sparsely between 4.0 and 6.5 with a high standard deviation (Fig. 5).

Table 3. Equivalent moment magnitude (M_w*) relations for different magnitude scales.

Relation	a ±2σ	b ±2σ	Number of Data	Magnitude Range	R^2
$M_w^* = a \cdot m_d + b$	+1.132 ±0.02	-0.541 ±0.12	1,484	2.8 – 7.3	0.81
$M_w^* = a \cdot M_L + b$	+1.030 ±0.02	-0.039 ±0.06	2,199	2.8 – 7.2	0.88
$M_w^* = a \cdot m_b + b$	+1.052 ±0.02	-0.156 ±0.07	940	4.0 – 7.0	0.88
$M_w^* = a \cdot M_s + b$	+0.844 ±0.04	+1.192 ±0.17	470	4.0 – 7.7	0.82
$M_w^* = a \cdot M + b$	+1.218 ±0.15	-1.044 ±0.63	55	3.4 – 6.9	0.58

3.3 Homogenization

The GOR results are implemented in all events in the study area. First M_w is searched and assigned as M_w* if found. For the events without an observed M_w, the first average magnitude with non-zero value is chosen according to the priority of saturation order in Table 1. For example, if an event has only average M_s and M_L values, M_s is selected for M_w* calculation. The chosen magnitude is also named M_x and used to calculate the equivalent moment magnitude (M_w*) with the relevant equation. After applying homogenization equations to all earthquakes, the catalogue is presented with a total of 45 parameters described in Appendix B. The catalogue has three sections: Event Origin Section, Magnitude Section and

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Comments. There are 23 parameters in the origin section. The origin time, coordinates and depths with their uncertainties are given. If one of these parameters is fixed, it is marked with the "f" flag. The magnitude section contains the average with standard deviation and median for the six magnitude scales. The selected M_x value, its source magnitude scale and calculated equivalent moment magnitude (M_w*) is presented. The ISC event ID number and the epicentre region are given in the comment section as the reference.

In the homogenised catalogue, 58% of the event origin parameters are flagged as *PRIME* by the ISC. The ISC and EMSC (CSEM) origin parameters are generally reported with the prime flag (~90-98%). On the other hand, approximately half of the reported parameters (~60-65%) by the national institutes in Turkey (KOERI, AFAD/DAD) and Greece (ATH) have the flag. The catalogue contains the origin information from the national sources (Fig. 6a) in a high number of percentages. The distribution of the magnitude scales for the equivalent magnitude calculation is given in Fig. 6b. The vast majority of M_w* are obtained from M_L and m_d; the contribution of the other magnitude scales is small.

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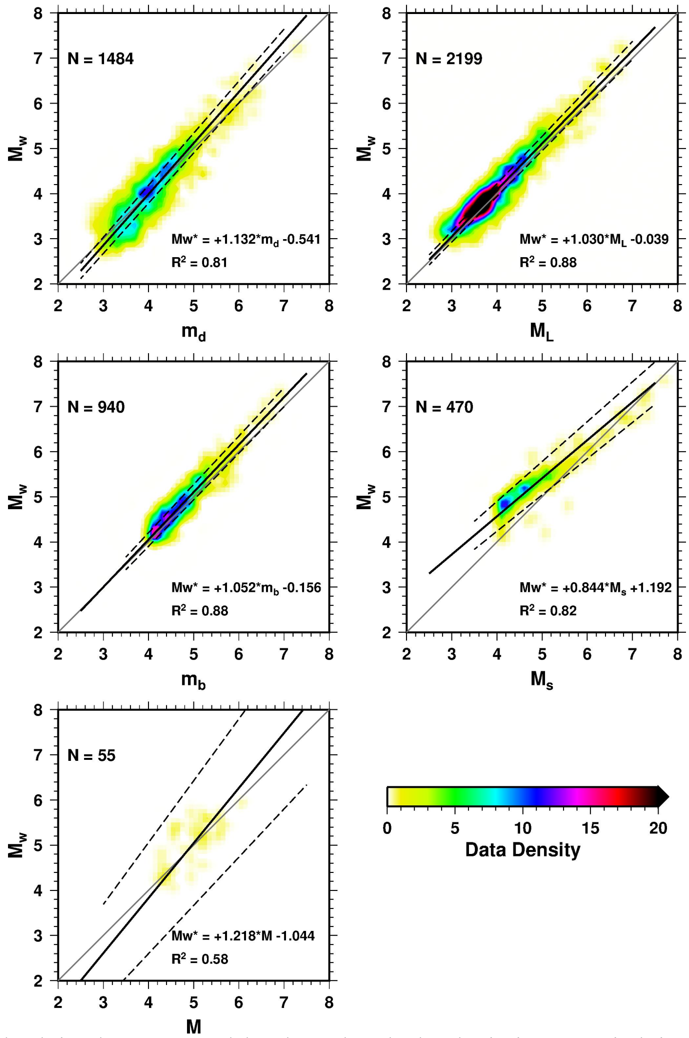

Figure 3. Magnitude relations between M_w and the other scales. The data density in 0.1 magnitude intervals is shown with coloured counters. N is the total number of magnitude pairs. The solid line is the best linear fit of the orthogonal regression, whereas the dashed lines show the 95% confidence interval after bootstrapping. Grey line indicates the y=x relation.

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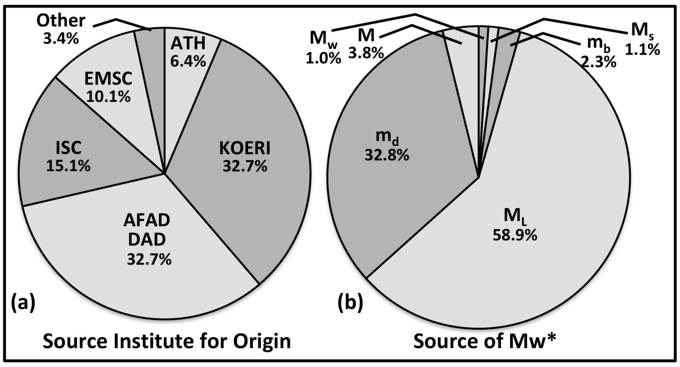

Figure 4. Distribution of the parameters in the homogenised catalogue. (a) Source institutes for the origin parameters. (b) Percentage of the magnitude scales used for M_w* calculation.

3.4 Completeness of the Catalogue

One of the important parameters of an earthquake catalogue is the magnitude of completeness (Mc). Mc is a threshold magnitude and indicates that all earthquakes with magnitudes greater than Mc are recorded in a study area. It is determined using the Gutenberg-Richter's (1954) cumulative frequency-magnitude law (GR). The GR relation is simple but powerful and formulated as $\log(N) = a - b \cdot m$, where N is the cumulative number of events with magnitudes equal to or greater than m. The other useful parameter derived from this equation is the *b-value* (slope). The *b-value* is around 1 for the tectonically active areas.

The modern instrumental period (1964-present) observation for the region shows a linear relation with $b = 0.96$ between the cumulative number of earthquakes and equivalent moment magnitude, M_w* (Fig. 7). If the dataset is extended to cover the period from 1900 to 1964, the linearity of the GR relation for the magnitudes between 5 and 7 disappears due to the magnitude calculation uncertainties and lack of small events in the catalogues for that time span. The Mc, the lowest intercept point of the linear fit with the slope b, is 2.7 for all earthquakes between 1964 and 2018.

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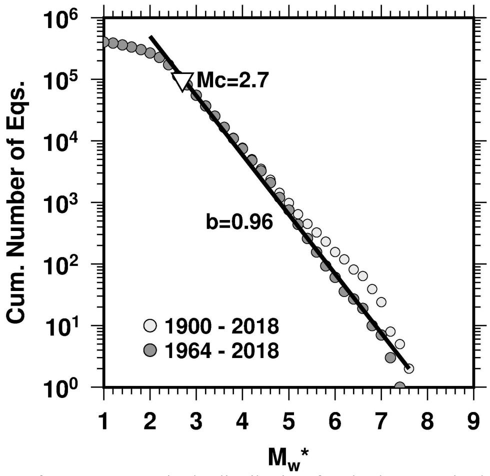

Figure 7. The Gutenberg-Righter frequency-magnitude distribution for the homogenised catalogue. Light and dark grey circles represent the cumulative number of earthquakes in the periods 1900-2018 and 1964-2018, respectively. The *b*-value and magnitude completeness (Mc) for the period of 1964-2018 are 0.96 and 2.7, respectively.

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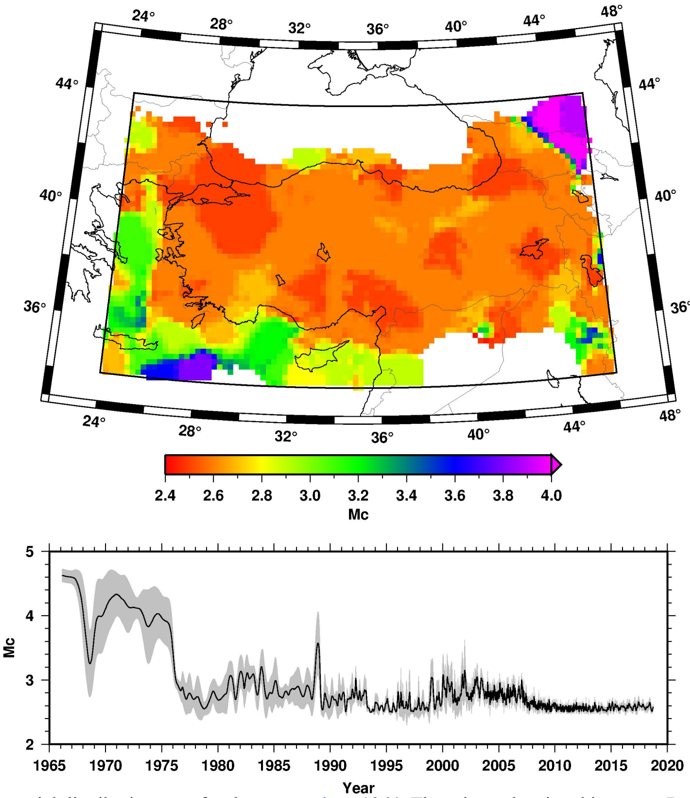

Figure 5. Top: Mc spatial distribution map for the events since 1964. There is no data in white areas. Bottom: Temporal Mc variation as a function of year. Grey area is the ±σ interval estimated by bootstrapping.

The maximum curvature method (Wyss et al., 1999; Wiemer, 2001) is applied to investigate the spatial and temporal change of Mc for the modern instrumental period. Equal horizontal sampling in latitude and longitude degrees is not used to prevent artificial elongation because the length of 1° of longitude is ~94 and ~76 km in south and north of the study area, respectively. I use 20 km grid spacing and at least 100 events in 100 km radius for the spatial distribution of Mc. On the other hand, the temporal variation is estimated using a window with 200 events and a moving-step of 40 events. These sampling parameters are sufficient to avoid erroneous statistical results for the *b-value* and Mc due to under-sampling and non-homogenous subsets (Amorese et al., 2010; Kagan, 1999, 2002, 2010; Kamer and Heimer, 2013; Shi and Bolt, 1982). The contour map in Fig. 8 shows that the homogenised catalogue is complete down to Mw* 2.6-2.7 around Turkey. The

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white areas have deficient seismic activity (see Fig. 2), and there is not sufficient data to ensure the criteria. The variation of Mc throughout the years indicates that the standard deviation band is narrow after the 1990s. The Mc is stable at about 2.6 since 2007 because the number of seismological stations increases after the devastating earthquakes ($M_w > 7$) in 1999.

4 Discussion

Generating an earthquake catalogue is one of the main study areas for seismologist. An institution that operates a costly seismological network provides the primary parametric information of an event from raw waveform observations. Although accessing catalogues is very easy via the internet in recent decades, it is difficult to obtain all available data due to some limitations of the data providers' web pages. The problems of online datasets, such as absence or limited observation for the past years, a limited number of parameters, lack of parameter uncertainties, listing limitations, useless formats in web pages make difficult to handle the earthquake data for an extensive range of users. However, most of the researchers pay only attention to the homogenised magnitudes and the number of events. Unfortunately, the importance of providing more parameters and their uncertainties in the previous catalogues are missed. For example, the SSG-9 (item #3.27i) safety document of the International Atomic Agency for nuclear power plant requires the uncertainties of all earthquake parameters. Therefore, the previously given datasets are less useful, especially for seismic hazard analyses.

The earthquake information for Turkey comes from two national networks operated by the KOERI and AFAD. Both institutes have a large number of stations around Turkey (~1240) and report recent events online. The date, time, depth and magnitudes without uncertainties can be obtained by using web search engines. While the KOERI lists only 50k events in a single search with a downloadable text file, the AFAD's search result is given with maximum of 100 events at each window, and it can be downloaded in the comma-separated CSV format. The other online catalogue with the same parameters is provided by the EMSC. The searched events can be downloaded in CSV format with the limitations of 5k lines. Among the three institutions, only the KOERI provides all available magnitude scales for an event. Additionally, the EMSC does not provide the type of magnitude scale for an event. On the contrary, the ISC provides all available parameters for an event determined not only by itself but also by the other institutions, as mentioned in the previous chapter. The magnitudes in the ISC event list are given in separate lines, so it is not easy to use without knowledge of the comprehensive bulletin format and programming. The online bulletin search of the ISC has also output limitation with 60k events.

Besides the online catalogues, some catalogue compilations based on magnitudes homogenization for Turkey and its vicinity are published. Leptokaropoulos et al. (2013) statistically analyse the earthquakes in Western Turkey (1964-2010) and construct a catalogue with an equivalent moment magnitude. They obtain conversion equations for different magnitude scales reported by different institutions. The catalogue contains 9875 events with only parameters of date, time, coordinates and focal depth. Kadirioğlu et al. (2018) present another homogenised catalogue for Turkey containing ~6573 events

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between 1900 and 2012 by utilizing the same dataset and conversion equations presented in the previous studies (Kadirioğlu et al., 2014; Kadirioğlu and Kartal, 2016). Their final catalogue is declustered and contains events only with M_w* > 4.0. On the other hand, Kadirioğlu et al. (2014, 2018) mention that a focal depth of 10 km is assigned to the events without reported depth or shallower than 1 km in the final catalogue. This assignment is arbitrary and unrecoverable. It may generate artificial errors in future studies using this catalogue, especially in seismic hazard analyses.

Burton et al. (2004) generate a homogenised catalogue that contains both reported and equivalent magnitudes for earthquakes in Greece and Western Turkey using the previous conversion equations. There are ~5200 events without Mc analysis. The catalogue by Bayliss and Burton (2007) contains ~3680 homogenised events in Bulgaria and the surrounding Balkan region with Mc ~4.0. More recently, Makropoulos et al. (2012) present homogenised ~7350 events for calculated M_s* and M_w* in the excel format for Greece and western Turkey.

The common structure of the previous catalogues mentioned above and others has limited earthquake parameters, such as date, location, depth and M_w*. Especially, the observed magnitudes and error/uncertainty values are not included. The source institute of the parameters is also missing. Therefore, it is impossible to trace back to the origin of the parameters and the equivalent moment magnitude (M_w*) cannot be recalculated using newly determined conversion equations. On the other hand, a truncated final earthquake list using a magnitude threshold is not useful for the researchers who want to analyse or plot all seismic activity in a region. The new homogenised catalogue in this study overcomes the common deficiency of the previous earthquake catalogues for Turkey.

5 Conclusions

Turkey and the surrounding area is one of the most seismically active regions on the Earth. Therefore, improved earthquake catalogue studies are necessary. A new, comprehensive, and homogenised earthquake catalogue is compiled in this study. The main aim is to present an earthquake database in an easily manageable ASCII format for a broad range of researchers. This study is based on the latest ISC Bulletin rebuilt in 2020. All earthquakes during the period from 1900 to October 2018 in Turkey and its near vicinity are analysed. The origin parameters and magnitude data in the IASPEI Seismic Format are systematically parsed with a Fortran algorithm.

Approximately 409k events in the study area bounded by 34° - 44° N and 24° - 46° E are compiled (Fig. 3). The equivalent moment magnitude (M_w*), which is the mandatory parameter for the seismic hazard studies, is calculated for all events. For this purposes, new conversion equations for m_d, M_L, m_b, M_s and M are determined using the well-refined magnitude pairs using the general orthogonal regression method that is useful when the two variables have different uncertainties. According to the values of M_w*, the overall catalogue is complete down to Mc = 2.7. The spatial completeness variation indicates Mc =

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~2.6-2.7 in Turkey. One of the advantages of the catalogue is that it is not declustered or truncated using a threshold magnitude to be useful for geophysicists, geologists and geodesists. The M_w* values can be easily recalculated, and the catalogue can be declustered by seismologists and earthquake engineers using different parameters. The final dataset contains not only M_w* as in the previous studies but also the average with standard deviation and median of the observed magnitudes. The ISC event ID-number and geographic region of each event are also given to trace an event in the bulletin. Presenting 45 parameters for all events is the most valuable part of the new homogenised catalogue.

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Appendix A

The ISC contributor institutes mentioned in this study is given below. The ISS and GUTE catalogues are used for the events in the period of 1900-1964.

Code	Institute
ISC	International Seismological Centre
ISS	International Seismological Summary [for 1900 - 1964]
GUTE	Gutenberg and Richter (1954) [for 1900 - 1952]
CSEM	European-Mediterranean Seismological Centre - EMSC (France)
ISK	B.U. Kandilli Observatory and Earthquake Research Institute (Turkey)
DDA	General Directorate of Disaster Affair (Turkey), until Sep.2017
AFAD	Disaster and Emergency Management Presidency (Turkey), since Oct. 2017
ATH	National Observatory of Athens (Greece)
THE	Dept. of Geophysics, Aristotle University of Thessaloniki (Greece)
MOS	Geophysical Survey of Russian Academy of Sciences (Russia)
TEH	Tehran University (Iran)
TAB	Tabriz Seismological Observatory (Iran)
TIF	Institute of Earth Sciences/ National Seismic Monitoring Center (Georgia)
SOF	National Institute of Geophysics, Geology and Geography (Bulgaria)
BUC	National Institute for Earth Physics (Romania)
SIGU	Subbotin Institute of Geophysics, National Academy of Sciences (Ukraine)
IPER	Institute of Physics of the Earth, Academy of Sciences, Moscow (Russia)
NSSP	National Survey of Seismic Protection (Armenia)
AZER	Republican Seismic Survey Center of Azerbaijan National Academy of Sciences (Azerbaijan)
NSSC	National Syrian Seismological Center (Syria)
THR	International Institute of Earthquake Engineering and Seismology (Iran)

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Appendix B

The first and second lines of the homogenised catalogue are the parameter names and column numbers, respectively. The earthquake parameters are given below.

Section	Column	Parameter	Section	Column	Parameter
Event Origin Section	1	Year	Magnitude Section	24	M (average)
	2	Month		25	Std.Dev. of M
	3	Day		26	M (median)
	4	Hour		27	m_d (average)
	5	Minute		28	Std.Dev. of m_d
	6	Second		29	m_d (median)
	7	Time Fix Flag		30	M_L (average)
	8	RMS (s)		31	Std.Dev. of M_L
	9	Latitude (°)		32	M_L (median)
	10	Longitude (°)		33	m_b (average)
	11	Location Fix Flag		34	Std.Dev. of m_b
	12	Semi-major Axis of 90% ellipse (km)		35	m_b (median)
	13	Semi-minor axis of 90% ellipse (km)		36	M_s (average)
	14	Depth (km)		37	Std.Dev. of M_s
	15	Depth Fix Flag		38	M_s (median)
	16	Depth Error (km)		39	M_w (average)
	17	Number of Stations		40	Std.Dev. of M_w
	18	Azimuthal Gap (°)		41	M_w (median)
	19	Closest Station Distance (km)		42	M_x
	20	Furthest Station Distance (km)		43	Source magnitude scale for M_x
	21	Event Type		44	M_w*
	22	Institute			
	23	Prime Flag	Comments	45	# (null)
				46	ISC information (event ID and region)

Fixing Flags: n: Not fixed (free), f: Fixed

Prime Flags: n: Not prime location, p: Prime location

Event Types: de: Damaging earthquake, fe: Felt earthquake,
ke: Known earthquake, se: Suspected earthquake,
uk: Unknown

Unreported numerical parameters in the ISC Bulletin are given as "0.00".

Uncalculated standard deviations are given as "-1.00".

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Data availability

The catalogue is available as the electronic material of this article.

Acknowledgments

I would like to thank Dr. Özlem KARAGÖZ TAN for her support and encouragement for this study. All maps and graphs are plotted using the Generic Mapping Tools (GMT) by Wessel and Smith (1998).

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