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Compilation and Earthquake Magnitude Homogenization to update the Libyan Catalogue

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ABSTRACT

The aim of this work is to compile and update a catalogue of the instrumentally recorded earthquakes in Libya, with uniform and homogeneous source parameters as required from the analysis of seismograms recorded by Libyan seismological network (LNSN) as well as earthquake recordings gathered from the international seismological center (ISC). This in turn requires a detailed analysis and comparison of the properties of different available sources, including the distribution of events with time and magnitude completeness and compilation of different magnitudes reported by ISC and LNSN. The observational data cover the time interval 1900 to 2018 and an area between 18° - 34° N and 8° - 26° E. Using the best linear relationship identified between the magnitudes and the seismic moment, and by analysis of relative seismograms recorded by LNSN we convert whenever possible the different magnitude types into moment magnitudes Mw. Analysis of the catalogue completeness based on the different types of magnitudes thus estimated, the interval of 1900 to 1972 appears to be complete for magnitudes ≥ 4.0 while the interval of 1973 to 2018 can be considered complete for magnitudes ≥ 3.0. An update of the Libyan seismicity map with the compiled catalogue data is thus can be constructed.

التجميع والتجانس في حجم الزلازل لتحديث الكتالوج الليبي

عبدالله عبدالله الميلادي نوفل نورالدين الشنطة عبدالمنعم عامر سويسى

يهدف هذا العمل إلى تجميع للبيانات وتحديث الكاتالوك وتجانس القوة الزلزالية للزلازل المسجلة في ليبيا، وهذا يتطلب الحصول على معلومات متجانسة للقوى الزلزالية من خلال تسجيلات الزلازل بالشبكة الوطنية للرصد الزلزالي (LNSN) وكذلك تسجيلات الزلازل التي يتم جمعها من المركز الدولي للزلازل (ISC). ويتطلب هذا بدوره تحليلاً مفصلاً ومقارنة لخصائص المصادر المختلفة المتاحة، بما في ذلك التوزيع الزمني للأحداث وحسابات القوة الزلزالية, وبتحليل التسجيلات الخاصة بالشبكة الوطنية للرصد الزلزالي وباستخدام أفضل علاقة خطية تم تحديدها بين قوة وعزم الزلازل نقوم بمعالجة البيانات المتحصل عليها من المركز الدولي للزلازل لغرض توحيد مقادير القوة الزلزالية المختلفة إلى قياسات العزم الزلزالي Mw. تغطي الدراسة الفترة الزمنية من 1900 إلى 2018 ومساحة تتراوح بين 20 ° - 34 ° N و 8 ° - 26 ° E. اكتمال الكتالوج مبني على أساس القيم المختلفة من القوة الزلزالية المتحصل عليها, حيث يلاحظ أن الفترة بين 1900 و 1972 مكتملة بالنسبة لمقاديرالقوة ≤ 4.0 في حين أن الفترة من 1973 إلى 2018 يمكن اعتبارها مكتملة بالنسبة للقوة ≤ 3.0. وهكذا يمكن بناء وتحديث الكتالوك الخاص بالزلازل المحلية لليبيا.

INTRODUCTION

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Libya is located at the northeastern part of the african continent and is bounded by main tectonic of the African Eurasian plate margin. The present day tectonic deformation within Libya is related to interaction and relative motions along these boundaries and their remote effects inside Libyan land. The majority of population settlements in libya are concentrated along the northern coast, and the predominant factor in terms of seismic hazard is generally related to the occurrence of moderate size earthquakes at short distances rather than large earthquakes that are known to occur at larger distances along the mediterranean offshore. Libya has a very long historical record of earthquakes going back about four millennia. Nevertheless, detailed and reliable information is available only for a few destructive events and their parameters have a limited accuracy. To prepare an earthquake catalogue as reliable as possible, which is a basic requirement for seismic hazard assessment as well as for any study of the characteristics of seismicity, the instrumental records constitute the main reference data set.

The territory of Libya is characterized by a moderate seismic activity and by the occurrence of small to moderate intra-plate events, while the large events generally take place to the north, offshore the Mediterranean Sea and toward Crete and Cyprus. Instrumental earthquake recording in Libya started as early as 1900; nevertheless, much of the seismic activity along its remote borders was not revealed. In order to compile a complete, homogeneous, and updated catalogue we compare and integrate our national data sources with the international seismological center catalogue (isc) that includes the published data from other regional and national networks.

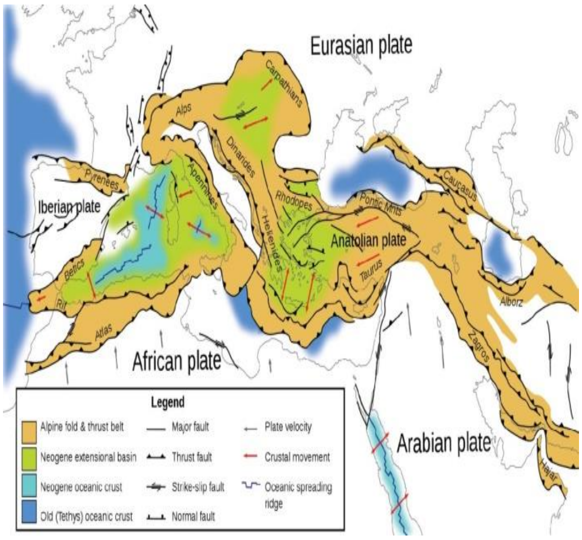

Figure 1. Showing african eurasian plate interaction and relative motions.

Tectonics of Libya

The tectonic frame of the african plate in the mediterranean is a result of convergence between africa and eurasia plates and the following formation of collisional belts along their margins. The **NORTH** african plate has sub ducted below the eurasian continent along the maghrebian-apennine front in the west and below the hellenic front in the east. The current state of stress of the libyan structures, revealed by seismicity in the region, in fact, two distinct styles are defined, the first, in the cyrenaica region and offshore which borders the mediterranean ridge and where low-energy earthquakes have p-axes ne-directed, shows the typical focal mechanisms of thrust faults and that they are aligned with the direction of tectonic convergence in the Aegean. The second, in new area where p-axes of high-energy seismic events are rotated to a new direction, is characterized by strike–slip motions. This suggests that the two areas are under the control of different stress regimes that can be related to different dynamic contexts. Figures 2 shows relative movement of tectonic plates and figure 3 shows main tectonic features in Libya.

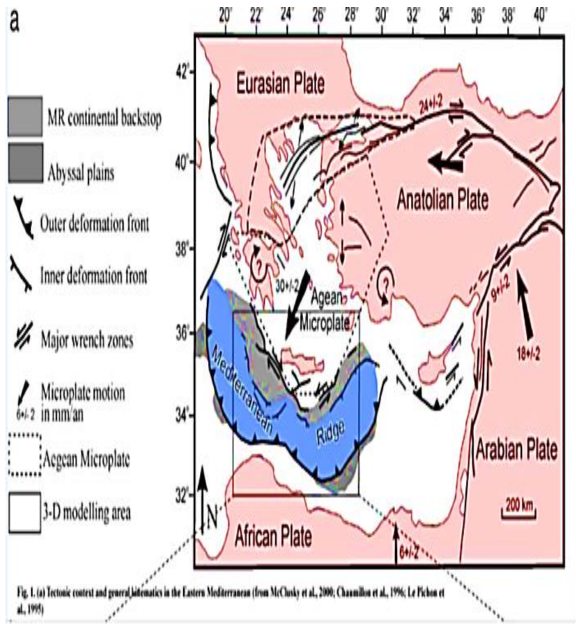

Figure 2. Tectonic context and general kinematics in the Eastern Mediterranean (McClusky et al., 2000; Chaumillon et al. 1996; Le Pichon al., 1995).

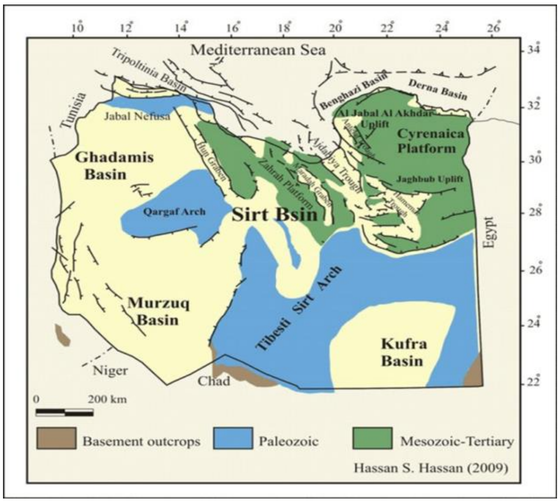

Figure 3. Tectonic map of Central Mediterranean Sea. Modified after Anketell (1992) and Finetti (1984).

Earthquake magnitude relationships for different earthquake

The most important way to define earthquake size is by using a magnitude scale. The usually quoted magnitude is the so called Richter magnitude. The idea behind the magnitude scale is that large earthquake will produce large amplitude seismic waves when measured with the same instrument and the same distance from the source with possible empirical corrections for the type of source or receiver region. Magnitude scales are defined using the following general form:

$$M = \log(A/T) + f(\Delta,h) + C\dot{s} + C\underline{r}$$

Where M = magnitude, A= ground displacement of the phase on which the scale is based, T=period of signal

F= correction for epicentral distance (Δ) and focal depth(h), $C\dot{s}$ and $C\underline{r}$ are corrections for source and receiver structure respectively.

The magnitude scales most used are:

1. Local/Richter magnitude (Ml) for period of 0.1 – 1.0s, $Ml=\log A -2.48+2.76 \log \Delta$
2. Body wave magnitude (mb) for period of 1.0 – 5.0s, $mp= \log (A/T)+Q (h, \Delta)$
3. Surface wave magnitude (Ms) for period of 20s, $Ms= \log A20s +1.66 \log \Delta + 2.0$
4. Moment magnitude (Mw) for period of ≥ 200s, $Mw= 2/3 \log M_o – 6.03$

$M_o= \mu$ S D (where D=rupture area)

Mw is the most physical earthquake magnitude as it is based on seismic moment M_o which is a direct measure of strength. It however requires a detailed analysis of the earthquake source process and is thus more difficult to obtain than other magnitudes that can be determined directly from the waveform.

Body wave magnitude, mb, is a world-wide scale determined by the maximum amplitude of the first few seconds (usually about one second) of short-period P waves on the vertical component seismogram. Surface wave magnitude, Ms, is a world-wide scale determined from the amplitude of surface waves (usually Rayleigh waves) with a period of about 20 seconds (Reiter, 1990).

For large earthquakes, mb saturates beyond magnitude 6.2 or so (Singh et al. , 1983) and cannot fully describe the strength of the large earthquakes that release energy along several kilometers of fault rupture (Reiter, 1990). Ms Scale tends to saturate and lose its validity for earthquakes beyond magnitude 8. This saturation of Ms scale may be attributed to extremely large source dimensions, generating extremely long period seismic waves. Clearly, the most appropriate magnitude scale to use in most aspects of seismic studies is moment magnitude, Mw, (Kanamori, 1977) which does not suffer from saturation, and has a sounder physical basis. However, Mw is available only for a very few portion of earthquakes.

Libyan National Seismological Network LNSN

At the end of the year 2005 the Libyan national seismological network (LNSN) starts functioning with 15 stations, of which 3 are very broadband STS2 seismometers and 12 are broad band trillium seismometers, figure 3 showing the locations of LNSN stations. The network is capable to detect local, regional and tele-seismic events.

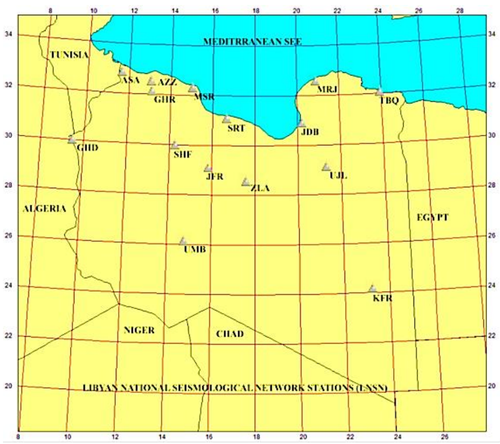

Figure 4. showing the locations of LNSN stations

Local and international data sources

The instrumental catalogue of Libya covers an area that lies between 20° - 34° N and 8° - 26° E and the period 1900–2018. The main sources used for compiling this catalogue are:

• Bulletins of the International Seismological Center (ISC) for the period 1900–2004.

• The Libyan national seismological network for the period 2005 – 2011.

• Bulletins of the International Seismological Center (ISC) for the period 2012 – 2018.

When merging different catalogues it is necessary to avoid the duplication of events eventually reported in more than one of the source catalogues; this can be achieved by carefully checking the possible double events (i.e. records which could be associated to the same earthquake) in the obtained catalogue. Table 1. showing the number of all magnitude type scales before homogenization.

Table 1. number of values of magnitude scales before homogenization

Magnitude Types in the catalogue before homogenization			
Magnitude type	**Number of events**	**Time period**	**Magnitude range**
MS	38	1907 - 018	3.1 – 7.1
mb	191	1907 - 018	2.4 -5.7
ML	295	1972 – 2018	2.4 – 4.8
MW	263	1968 – 2018	3.1 – 6.4

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The possible common events, with origin time difference less than 1 min and location difference less than 1 degree for latitude and longitude, have been first identified. All the records satisfying such conditions have been examined manually, to analyze specific cases. If the same event was listed with different coordinates and origin time, the parameters estimated from local records have been used; otherwise, the parameters from the ISC catalogue have been considered. The depth is not taken into consideration, due to the large errors affecting this quantity. Moreover, the straightforward merging of the data sources mentioned above would yield a heterogeneous earthquake catalogue, with different magnitude types, not always comparable. Table 2 shows the earthquake magnitude at which the catalogue is complete.

Table 2. shows the earthquake magnitude completeness of catalogue.

Time interval	No. of events	Magnitude range	No. of years	Completeness of Catalogue
1907 - 1980	44	3.2 – 7.1	73	≥ 6.0
1981 - 2004	130	3.0 – 6.4	23	> 4.0
2005 - 2012	515	3.0 – 5.4	7	≥ 3.0
2013 - 2018	97	3.0 – 5.1	5	≥ 4.0

Data analysis and Estimation of parameters

In general, magnitude is a logarithmic measure of the size of an earthquake or explosion based on instrumental measurements. The magnitude concept was first proposed by Richter (1935). Magnitudes are derived from ground motion amplitudes and periods or from signal duration measured from instrumental records. After the deployment of the World Wide Standardized Seismograph Network (WWSSN) in the 1960s it became customary to determine earthquake magnitude ground motion measurements from medium- and long-period seismographic recordings of both surface waves, and different types of body waves, in the teleseismic distance range. Therefore, Gutenberg and Richter provided correlation relations between various magnitude scales. There is no a priori scale limitation to magnitudes as exist for macroseismic intensity scales.

The scalar seismic moment $M_{0,}$ is proportional to the average static displacement and the area of the fault rupture and is so a good measure of the total deformation in the source region, the quantitative measure of the size and strength of a seismic shear source is the scalar seismic moment M_0. The determination of the scalar seismic moment M_0 on the basis of digital broadband records is becoming increasingly standard at modern observatories and network centers. This applies not only to very strong and teleseismic events but also to comparable scaling of moderate and weak events, both in the teleseismic and the local/regional range.

The definition of the magnitude entails that it has no theoretical upper or lower limits. However, the size of an earthquake is limited at the upper end by the strength of the rocks of the earth's crust. At the other extreme, highly sensitive seismographs can record earthquake with a magnitude of less than -2. These magnitudes are systematically underestimated as compared to moment magnitudes Mw determined from $M_{0.}$ No $M_S > 8.5$ has ever been measured although moment magnitudes up to 9.5 to 10 have been observed. This effect is termed magnitude saturation, this saturation occurs much earlier for mb, which is determined from amplitude measurements around 1 Hz. No mb > 7 has been determined from narrowband short-period recordings, even for the largest events.

To compile a uniform catalogue of earthquakes, necessary for seismic hazard assessment, as well as for any analysis of the space-time properties of seismicity, we decided to estimate the moment magnitude Mw as the size of as many of the earthquakes in the final catalogue of Libya as possible, because Mw is a parameter directly related to the source physics and it is expected to become increasingly available in the future.For earthquakes recorded by ISC and since we haven't the seismogram wave form data we will use a specific linear relation.

The moment magnitude Mw can be derived from the scalar seismic moment Mo (in Nm) using the relations of Kanamori (1977):

$$Mw = (2/3) \log M_o - 10.7 \quad (1)$$

In order to convert the different kinds of magnitude into moment magnitude, the study of Grünthal, G., Wahlström, R. (2012): The European-Mediterranean Earthquake Catalogue (EMEC) for the last millennium. The best linear relations between different kinds of magnitude and the available magnitude types during the different periods are considered. Linear relationships were developed for *m*b, *M*S, and *M*L versus *M*w magnitude, when respective magnitudes of overlapping events were used as input data. For Libya we could at least use several publications by Ambraseys. *M*s and/or *m*b are given for catalogued events in Tripolitania, Libya, in 1900-1976 (*Ambraseys* 1984). *M*s magnitudes from *Ambraseys* (1994) for all Libya in the time period 1900-1990 were converted with the following relations. Also some events in *Ambraseys et al.*(1994) fall in Libya and western Egypt polygon. Lacking access to more local data, data from ISC bulletins were used for the polygon Libya and western Egypt.

By using the relation derived by *Kalafat et al.* (2010) vs. *Godzikovskaya* (2001) ML was converted to Mw as following

$$Mw=0.65*ML+1.90 \quad (2)$$

*m*b was converted to *M*w as derived by *GWS09* after *Utsu* (2002) based on global data with the following relation:-

$$Mw = 8.17 - sqrt(42.04 - 6.42*mb) \quad (3)$$

Ms was converted to Mw using the relation obtained by regression of *Papazachos et al.* (2003):-

$$Mw = (0.796 * Ms) + 1.28 \text{ for } Ms \geq 5.4 \quad (4)$$

$$Mw = (0.585 * Ms) + 2.42 \text{ for } Ms < 5.4 \quad (5)$$

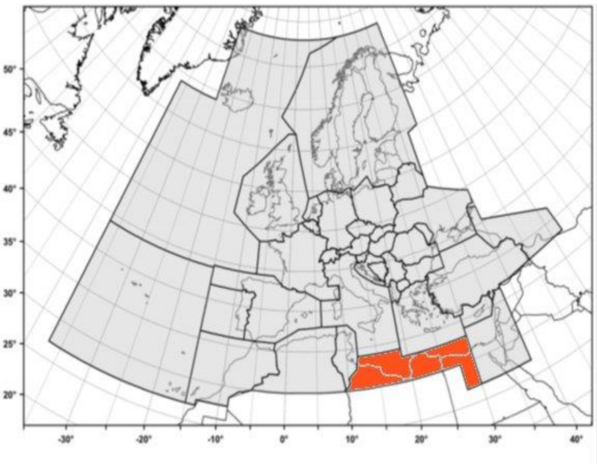

Figure 5. The polygons used for the generation of The European-Mediterranean Earthquake Catalogue EMEC (G. Grünthal, R. Wahlström, Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences).

METHOD OF ANALYSIS

All events used in this study were reformatted from Nanometrics SEED format, to GSE format, using the Wavetool program provided by Seisan software (Jens Havskov). This program enables us to choose between displacement, velocity and acceleration seismograms. For our study displacement seismograms were used, all events were reformatted to SACA format using Cygwin (codeco) program to be readable with MatLab program. Spectral analysis was performed using MatLab program, to remove low frequency signal components Butterworth high pass filtering was applied to the original SACA formatted seismograms.

In order to create a uniform catalogue in terms of *M*W magnitude, the following procedure was applied:

1- If *M*w is available: use *M*W
2- If *M*w is not available and *M*S ≥ 5.4: use equation (4)
3- If *M*w is not available and *M*S < 5.4: use equation (5)
4- If *M*w is not available and *m*b is available: use equation (3)
5- If *M*W, *M*S and *m*b are not available and *M*L is available use equation (2)

For earthquake recorded by LNSN of which we have the wave form data we use the following procedures to estimate the Mw: The single measure of the earthquake size is the seismic moment magnitude Mw. It does not saturate for big events because it is based on seismic moment M_0, which is made from the measurement of the (constant) level of low-frequency spectral displacement amplitudes for $f << f_0$, this level increases linearly with M_0. In order to calculate $M_{0,}$ local earthquake data recorded by Libyan National Seismological Network (LNSN) was analyzed. The LNSN uses a broad-band frequency recording instruments and the most advanced processing and interpretation programs (Seisan). Earthquakes of magnitudes ≥ 3.0 are used in this study. Only events recorded by at list three stations are processed. The ground displacement seismograms are used in the analysis. Fourier spectra of original seismograms are corrected for the effects of attenuation to get corrected source spectra. The low-frequency values are scaled to seismic moment M_0, and moment magnitude Mw is then calculated. Three-component filtered time history seismograms plotted so that the appropriate time window for both P- and S-waves could be selected. Figure 5 shows an example of three-component of the event of 22-5-2008, for UJL- station. The epicentral distance was about 385 km. P-wave and S-wave time windows were selected to calculate the spectrum. The resultant spectral plots for both P- and S-waves, are shown in Figure 6.

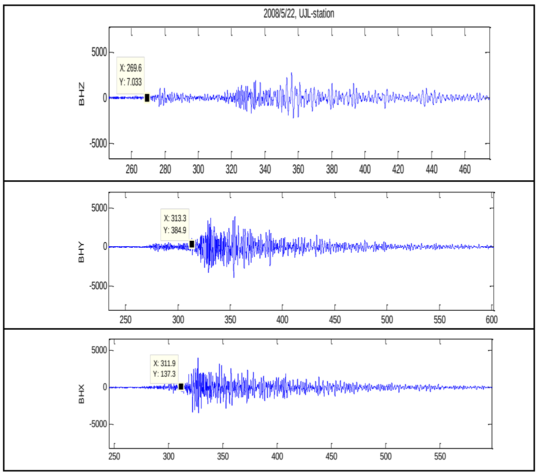

Figure 6. The three components seismogram, of the 22-5-2008, UJL-Station.

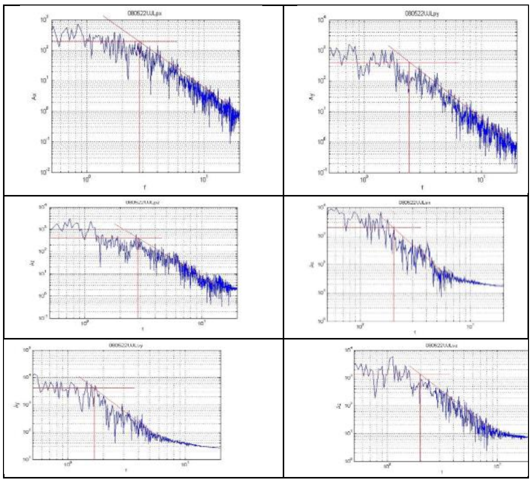

Figure 7 the results of spectral analysis for both P- and S-waves.

The scalar Seismic moment is:

$$M0 = \mu D A \quad (6)$$

Where μ is the shear modulus at the source; D is the average source dislocation and A is the size of the rupture plane.

Under the assumption of a homogeneous Earth model and constant velocity C, the seismic moment M0 can be determined from the relationship:

$$M0 = 4 \pi C3 \rho r \Omega_\circ / Fc Rc Sc \quad (7)$$

With, r is the epicentral distance, ρ is the average density of crust, $\Omega_\circ$ is the low-frequency level of the displacement spectrum, Rc is the average radiation pattern and Fc is the free-surface effect, the effect of the free surface assumes a vertical incidence, which is an approximation. However, due to the low velocity layers near the surface, the incidence is not far from vertical. The effect is the same for P and S-waves. And Sc is the site correction. M0 is expressed in the unit Nm=kg m2 s-2.

Moment Magnitude is defined by the following formula:

$$Mw = (2/3) \log M0 - 6.033 \quad (8)$$

RESULTA AND DISCUSSION

Results:

We note that in earlier time there were no moment magnitude (Mw) values given in the international catalogues, and the only magnitude values are given in the form of surface, body and local magnitudes, later in time some of the international seismological networks started to use moment magnitude in their catalogues as it became known to be the most physical and reliable description of earthquake magnitude.

After installation of Libyan National Seismological Network in the beginning of the year 2005, so we could have the waveform data, and by spectral analysis of seismograms moment magnitudes became Table 3 showing the number of moment magnitude (Mw) values obtained from data either Mw directly from given data or transferred from other magnitude read types to Mw.

Table 3. showing the number of moment magnitude (Mw) values

Mw Source	1907 -1980	1981 -2004	2005 -2010	201 1-2018
Direct read ISC Mw	0	4	47	7
Mw from spectral analysis	0	0	239	13
Mw converted from Ml	7	47	31	53
Mw converted from mb	16	26	148	0
Mw concerted from Ms	14	7	1	0

Discussion and conclusions

We compiled a unified earthquake catalogue of Libya for the period 1900–2018, using all the national and international sources available to us. The data of that catalogue include the location of events, their magnitudes, in addition to macro-seismic information of some significant earthquakes during the early instrumental era (1900–2005).

Accordingly, the number of events increased from 219 in the first period of observation 1900–2005 to 570 in the period from 2005 to 2018. The ISC represent the main source of the surface (MS) and body (mb) wave magnitude values used in our analysis.

The magnitudes included in the second period were local magnitude ML, moment magnitude Mw. In the period from 2005 to 2018, the number of events increased rapidly due to seismological networks distribution spread worldwide. Figure 8 shows the plots of different types of magnitudes verse moment magnitude using the best linear relations between different kinds of magnitude obtained by the research of The European-Mediterranean Earthquake Catalogue (EMEC) for the last millennium.

Figure 8 relations between different types of magnitudes verse moment magnitude. In this work, we converted the various reported magnitudes into moment magnitude, using a multi-step approach. However, the significant decrease in the threshold magnitude for the second period is mainly due to the LNSN seismological stations installation and the improvements in the techniques of analysis

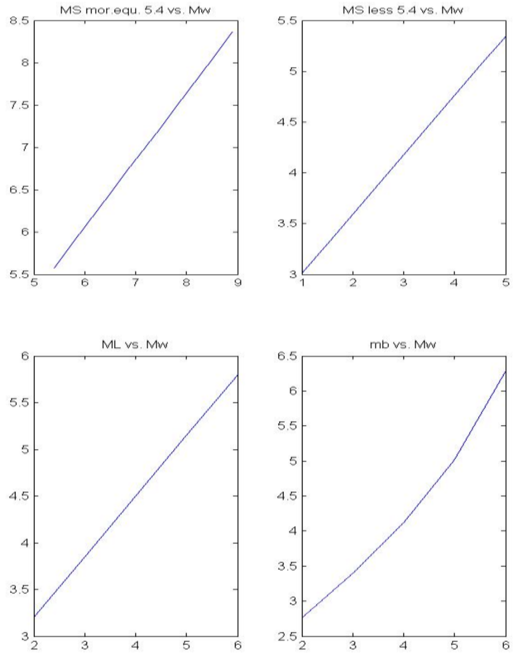

Figure 8. relations between different types of magnitudes verse moment magnitude.

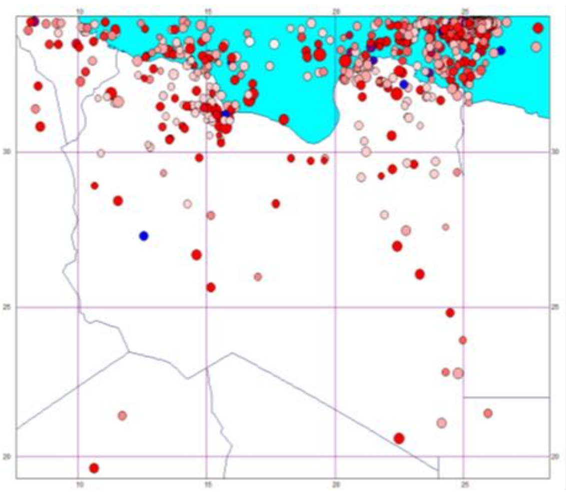

Figure 9 shows seismicity map of Libya as drawn from the Libyan earthquake Catalogue, moment magnitude values ≥ 3.0 .

From figure 8 we conclude that local magnitude ML is under estimated for magnitude values ≤ 4.5 and is overestimated for magnitude values ≥ 4.5, while body wave mb magnitude is under estimated for magnitude values ≤ 4.0, linear between 4.0 and 5.0 and under estimated for magnitude values ≥ 5.0, surface wave magnitude MS is under estimated for magnitude values ≤ 4.5 and over estimated for magnitudes of ≥ 4.5.

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