INTEGRATION AND MAGNITUDE HOMOGENIZATION OF THE EGYPTIAN EARTHQUAKE CATALOGUE

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Abstract

The aim of the present work is to compile and update a catalogue of the instrumentally recorded earthquakes in Egypt, with uniform and homogeneous source parameters as required for the analysis of seismicity and seismic hazard assessment. This in turn requires a detailed analysis and comparison of the properties of different available sources, including the distribution of events with time, the magnitude completeness and the scaling relations between different kinds of magnitude reported by different agencies. The observational data cover the time interval 1900-2004 and an area between 22°-33.5°N and 25°-36°E. The linear regressions between various magnitude types have been evaluated for different magnitude ranges. Using the best linear relationship determined for each available pair of magnitudes, as well as those identified between the magnitudes and the seismic moment, we convert the different magnitude types into moment magnitudes $M_W$, through a multi-step conversion process. Analysis of the catalogue completeness, based on the $M_W$ thus estimated, allows us to identify two different time intervals with homogeneous properties. The first one (1900-1984) appears to be complete for $M_W \geq 4.5$, while the second one (1985-2004) can be considered complete for magnitudes $M_W \geq 3$. 
Introduction

Egypt is located at the northeastern part of the African continent and is bounded by three main tectonic elements (Fig. 1): the African Eurasian plate margin; the Red Sea plate margin; the Levant transform fault. The present day tectonic deformation within Egypt is related to interaction and relative motions along these boundaries and their remote effects inside Egyptian land. The majority of population settlements in Egypt are concentrated along the lower Nile valley and the Nile Delta, and the predominant factor in terms of seismic hazard is generally related to the occurrence of moderate size earthquakes at short distances (i.e. the Cairo earthquake in 1992, reported with mb=5.8 and Ms=5.3 in the ISC catalogue), rather than large earthquakes that are known to occur at larger distances along the northern Red Sea and the Gulf of Suez (e.g. the Sheldwan earthquake in 1969, with mb=6.1 and Ms=6.9 according to USGS; the Gulf of Aqaba earthquake in 1995, with mb=6.2 and Ms=7.2 in ISC), as well as in the Mediterranean offshore (i.e. the Alexandria earthquake in 1955, reported with mb=6.1 and Ms=6.8 by USGS; the Cyprus earthquake in 1996, with mb=6.3 and Mw=6.8 in ISC; the Ras El-Hekma earthquake in 1998, having mb=5.8 and Mw=5.6 in ISC).

Egypt 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. An overview of the history and development of the Egyptian seismological network is provided hereinafter.

The seismicity of Egypt has been studied by several authors (e.g. Sieberg, 1932; Ismail, 1960; Gergawi and El-Khashab, 1968; Maamoun et al., 1984; Kebeasy, 1990; Abou Elenean, 1997). The compilation of an earthquake catalogue for the instrumental data, as reported during the time interval 1900 - 1984, was first achieved by Maamoun et al. (1984). They collected the arrivals associated with the local events, recorded within 500 km from the neighboring stations, and then located the epicenters of those events using the P-arrivals recorded at least in three stations with one or more S-P arrival times. The catalogue also includes the strongest earthquakes reported by the international data centers (ISS, ISC and USGS), which were recorded by several stations.

The territory of Egypt 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 farther east, along the northern Red Sea or Gulf of Aqaba, and to the north, offshore the
Mediterranean Sea and towards Crete and Cyprus. Instrumental earthquake recording in Egypt started as early as 1899, 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, such as Israel.

**History of the Egyptian seismological network**

Instrumental recording at Helwan (HLW) started by an E-W component Milne-Shaw seismograph in 1899. An additional N-S component of the Milne-Shaw type and a vertical component of Galitzin-Willip seismographs began recording in 1922 and 1938, respectively. In 1955 another set of short period Sprengnether seismographs was also added. In May 1962, the Helwan seismic recording system was replaced by Benioff short period and Sprengnether long period seismographs, operating as one of the World Wide Standardized Seismograph Network (WWSSN) stations. In December 1972, a Japanese three-components short period seismograph system, with ink writing stylus recording drums, was installed. In late 1975 three additional permanent stations, equipped with photographic recording systems, were installed at Aswan, Abu-Simbel and Mersa-Matrouh. These stations have three-component short period seismometers of CVKM3 and CHKM3 type, used at the Standard Russian World Wide Stations. Moreover, the Aswan station was equipped with an additional three-component long-period seismograph system, composed of CVKM3 and CHKM3 type seismometers.

In July 1982, a radio-telemetered network of nine vertical short period (S-13, Geotech-Teledyne) stations was operated for monitoring micro-earthquake activity around the northern and western parts of Lake Nasser after Kalabsha earthquake of November 14, 1981. This network was expanded to thirteen stations and two of them were equipped with horizontal components by 1985. Four short period (MEQ equipped with SS-1 ranger) single vertical component seismograph stations were added during the period from 1986 to 1990 at Kottamia (KOT), Hurghada (HUR), Tel El Amarna (TAS) and Mersa Alam (MRA). Since August 1991 a very broad-band station (KEG) was erected at Kottamia as a part of the Med Net Project. In cooperation with the International Institute of Seismology and Earthquake Engineering (IISEE), Japan and the National Research Institute of Astronomy and Geophysics (NRIAG), a local network of ten telemetered short period (L4C, Mark-product) seismic stations, was installed in August 1994 around the southern part of the Gulf of Suez. Figure 2 shows the distribution of seismological stations in Egypt up to 1994. Since the occurrence of the Cairo
earthquake, in October 1992, the Egyptian National Seismological Network (ENSN) project started, with the aim to cover all of the Egyptian territory (Fig. 3). The ENSN started operating in August 1997 and since then accurate parameters of a relevant seismic activity have been determined.

**Local and International Data Sources**

The instrumental catalogue of Egypt covers an area that lies between 25°- 36°E and 22°- 33.5°N and the period 1900-2004. Figure 4 displays the geographical distribution of the epicenters for events included in the available catalogue. The main sources used for compiling this catalogue are:

- Seismicity of Egypt for the period 1900-1984 as reported by Maamoun et al. (1984).
- Bulletins of the International Seismological Center (ISC) for the period 1985-2004, that include the data of Institute for Petroleum Research and Geophysics of Israel (IPRG).
- The final report of the project “Determination of the active seismic sources in Arab Republic of Egypt” (Kebeasy et al., 1996), for the period 1989-1993.
- The seismological bulletin of Hurghada Seismograph Network (HSN), Nos. 1&2 (Marzouk et al., 1996), with observational data covering the period from August 1994 to December 1997.
- The yearly bulletins of the Egyptian National Seismological Network (ENSN), for the period from 1998 to December 2004.

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 (Primakov and Rotwain, 2003). Accordingly, the merging procedure has been performed as follows. The possible common events, with origin time difference less than 1 minute and location difference less than 1 degree for latitude and longitude, have been first identified. All of the records satisfying such conditions have been
examined manually, to analyse specific cases. If the same event was listed with different coordinates and origin time, the parameters estimated from local records (i.e. national and regional catalogues) have been used; otherwise, the parameters from the ISC catalogue have been considered. The depth is not taken into consideration, due to 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. Specifically, in Egypt and surrounding regions the most frequently reported estimates are the magnitude types given by the local catalogues, that is: M(HLW), M_L(IPRG), M_D(HLW) and M_L(HLW). In addition to these magnitudes, m_b and M_s, as reported in USGS and ISC global catalogues, are also listed for moderate to large events. Therefore, when using the unified earthquake catalogue, the problem arises of the selection of an operating magnitude as representative and homogeneous as possible through the whole data set.

The M(HLW), which is the dominating magnitude type in the time interval from 1900-1984, was evaluated directly from the average maximum amplitudes of ground motion A (in $\mu m$), recorded on the two horizontal components, without simulating the Wood Anderson seismograph, as follows (Maamoun, 1978):

$$M(HLW) = \log A + 2.51 \log D - 2.37$$

where D is the epicentral distance (km) that varies between 120 km and 1100 km.

The M_L(IPRG) is frequently listed for earthquakes which occurred within the time interval 1984 up to now and computed for events with $M_L \leq 5.0$ and $D \leq 1000$ km using the following relation (Shapira, 1988):

$$M_L(IPRG) = -0.6 + 0.0015D + 2 \log T$$

where, D is the epicentral distance (km); T is the time interval in sec between the arrival of the S wave and until the ground motion falls and stays below 0.5 $\mu m/s$. However, this magnitude type is originally correlated with a sample of $M_L$ values based upon amplitude measurements from short period seismograms, simulating a Wood-Anderson instrument, as explained by Shapira (1988).

$M_D(HLW)$ was estimated from the total duration (minute) of the recorded signal, and was mostly used at Helwan during the time interval from 1985-1998. This type of magnitude was defined for two distance ranges ($D \leq 300$ km, $300 \leq D \leq 1200$ km) by Lee et al. (1972) and Maamoun (1978) respectively, as follows:
\[ M_\text{D(HLW)} = 2.0 \log t + 0.0035 D - 0.87 \quad \text{for } D < 300 \text{ km} \]  
\[ M_\text{D(HLW)} = 1.16 \log t + 0.00085 D + 3.2 \quad \text{for } 300 \leq D \leq 1200 \text{ km} \]

where \( D \) is the distance in kilometers and \( t \) is the total duration of oscillation in minutes.

The principal magnitude type now in use at Helwan for the ENSN is \( M_\text{L(HLW)} \). It is estimated, relying upon the maximum observed amplitude on the horizontal components simulating a Wood-Anderson seismograph response, by the following equation:

\[ M_\text{L(HLW)} = \log A + 2.56 \log D - 1.67 \]

where \( A \) is the maximum trace amplitude in millimeters and \( D \) is the epicentral distance (km).

A preliminary analysis of the compiled catalogue is performed in order to describe the distribution of earthquakes as a function of time and magnitude, during the period 1900-2004 (Fig. 5). In view of the heterogeneity of the magnitude types reported in the catalogue, during the different time periods, this analysis is performed by simply referring to the maximum magnitude (\( M_{\text{max}} \)) among all of the available magnitude estimates. The total number of events in the compiled catalogue is 15875.

Based on the time distribution of the seismic activity four intervals can be identified: interval I, the pre-WWSSN Helwan station before 1962; interval II for the period 1962-1984; interval III, covering the period between 1985 to 1997, and interval IV for the period 1998-2004 when the ENSN started to operate. During the first time interval, the activity has a stable rate without any noticeable change and the annual number of events is lower than after 1962. The total number of the recorded events with \( M_{\text{max}} > 3.0 \) is \( N = 82 \). Figure 5 also shows that the annual number of earthquakes after 1962 is characterized by a gradually increasing trend. During the second time interval, the number of recorded events increased to 289 events, with a limited number of events with a \( M_{\text{max}} < 3.0 \), due to the installation of WWSSN Helwan seismograph station. The largest peak of activity occurred during 1969-1970, representing the aftershocks of the 1969 Shedwan earthquake (\( m_b = 6.0 \)). The visible increase in the activity after the 1981 Aswan earthquake is mainly related to the installation of the Aswan Seismological Network, which detected a large number of events that are mainly micro-earthquakes. The yearly rate for the earthquakes reflects an abrupt increase in the number of the events for all the magnitude ranges after 1984 i.e. the third and fourth stages. Although these two stages have shorter periods, 13 and 6 years, respectively, the number of events is much larger than the other periods. Through time interval III a number of 5785 events were reported, while the number of the recorded events in the last stage (interval IV), increased to
9719 events. The considerable increase in the seismicity rate through III and IV stages and the remarkable number of small events during the period 1985-2004 are due to the installation of a large number of stations in Egypt and surrounding regions, in addition to the high activity associated with the aftershocks of some significant earthquakes and particularly, Cairo 1992, Aqaba 1993 and 1995 earthquakes and their seismic sequences. The year 1998 constitutes a milestone due to the introduction of the ENSN network and its contribution for monitoring the seismic activity in Egypt. Figure 5 reflects the abrupt increase in the activity after the installation of ENSN. The majority of earthquakes in the compiled catalogue correspond to the small events recorded during the recent instrumental period (since 1998), which are generally quantified by means of $M_L(HLW)$ and $M_L(IPRG)$ magnitude types.

Data Analysis

In order to produce a catalogue with a homogeneous earthquake magnitude estimate, starting from the heterogeneous set of available magnitudes from different sources, it is necessary to perform the following steps (Peresan and Rotwain, 1998):

a) to study the relations between different kinds of magnitude reported in the catalogue, in order to have a formal rule for the choice of any relation that can be applied for magnitude conversion, resulting into an acceptable homogeneity of the catalogue;

b) to study the completeness of the catalogue to find the magnitude thresholds above which the different data sets, as well as of the resulting catalogue over the investigated time period 1900-2004, are complete. A preliminary investigation can be performed by drawing plots of the frequency of earthquakes versus magnitude, in accordance with the magnitude-frequency relationship by Gutenberg and Richter (1944):

$$\log N = a - b M$$

(6)

Relations between different magnitude types

To define a homogeneous magnitude type for the newly compiled catalogue, linear regression relations between the different magnitude types are considered. In the following section, we will identify the calibration relations between the different magnitude types used by different agencies in various periods. The equations for linear fitting are provided along with the relevant statistical parameters, such as: the percentage $P$ of points outside two standard deviations, $2\sigma$, the correlation coefficient, $R$, the standard deviation for the parameters $A$ and $B$ of the linear fitting and the RMS values. The fitting parameters have been obtained in this study using orthogonal regression, where the fitting parameters are estimated
as the values which minimize the perpendicular distances from the data points to the fitted line.

The relations obtained in this study are illustrated for the different magnitude types. The association of equivalent events from different data sets is done using specific software as well as by manual inspection. The selection of the common events is based on differences in origin time less than 1 minute and less than 1 degree for latitude and longitude. All of the records satisfying such conditions have been examined manually, to detect possible mis-associations and to verify specific cases.

1. **M_L(IPRG) - m_b(ISC) relation:**
   Linear regression for the data set within the magnitude range $3.8 \leq m_b \leq 6.1$ gives the following relation (Fig. 6):
   \[ M_L(IPRG) = (0.69 \pm 0.07) m_b(ISC) + (1.67 \pm 0.29) \]
   with $N = 115$, $RMS = 0.35$, $R = 0.70$ and $P = 6.08 \%$.

2. **M_D(HLW) – m_b(ISC) relation**
   We have established the relation between $M_D(HLW)$ and the corresponding $m_b(ISC)$ for 100 earthquakes. We have obtained a linear regression relation (Fig. 7) for the magnitude range $3.0 \leq m_b \leq 6.1$ as:
   \[ M_D(HLW) = (0.61 \pm 0.05) m_b(ISC) + (1.80 \pm 0.20) \]
   with $N = 100$, $RMS = 0.28$, $R = 0.80$ and $P = 7 \%$.

   For the same range of magnitudes, to compare the $M_D(HLW)$ estimated by equation (8) with that estimated by the scaling relation of Maamoun et al. (1984):
   \[ M_D(HLW) = (0.83 \pm 0.07) m_b(ISC) + (0.75 \pm 0.34) \]
   the histogram representing the difference between the $M_D(HLW)$ estimated by equations (8) and (9) (Fig. 8) has been constructed and it shows that these differences are within the range ±0.1 (i.e. well below the errors generally affecting magnitude estimates) for the majority of earthquakes.

3. **M_L(HLW) – m_b(ISC) relation:**
   The relation derived between $M_L(HLW)$ and $m_b(ISC)$ is:
   \[ M_L(HLW) = (1.07 \pm 0.58) m_b(ISC) + (0.01 \pm 2.36) \]
   with $N = 13$, $RMS = 0.46$, $R = 0.49$ and $P = 0 \%$. 
This regression relationship does not appear satisfactory and cannot be used as a conversion relation.

4. MD(HLW) – ML(IPRG) relation:
   A further relation has been obtained, between MD(HLW) and ML(IPRG), by considering 423 events within the magnitude range $1.7 \leq ML(IPRG) \leq 5.8$. The relationship (Fig. 9) displays a good correlation with the following parameters:
   
   $MD(HLW) = (0.60 \pm 0.02) ML(IPRG) + (1.47 \pm 0.07)$  \hspace{1cm} (11)
   
   with $N = 423$, RMS = 0.24, $R = 0.82$ and $P = 5.2 \%$.

5. ML(HLW) – ML(IPRG) relation:
   Furthermore, for the 106 events extracted from the catalogue since 1998 we obtain a linear relation (Fig. 10) as follows:
   
   $ML(IPRG) = (0.64 \pm 0.07) ML(HLW) + (0.91 \pm 0.21)$  \hspace{1cm} (12)
   
   with $N = 106$, RMS = 0.40, $R = 0.67$ and $P = 3.77 \%$.

6. mb – MS relation:
   Within the magnitude range, $3.7 \leq mb \leq 6.4$ we obtained the following calibration relation (Fig. 11) between $mb$ and $MS$ magnitudes. The number of events corresponds to the earthquakes having both $mb$ and $MS$ reported in ISC and PDE catalogues:
   
   $MS = (1.3 \pm 0.14) mb - (1.84 \pm 0.73)$  \hspace{1cm} (13)
   
   where $N = 40$, RMS = 0.53, $R = 0.83$ and $P = 2.5 \%$.

7. ML – Mo relation:
   In addition to the empirical relations that have been introduced in sections 1 to 6, we calibrate the seismic moment, $Mo$, with the local magnitude $ML$ and with the duration magnitude of Helwan $MD(HLW)$. $ML$ data used in establishing this relation correspond to $ML(IPRG)$ in addition to $ML$ for 56 events estimated by Abd-El Wahed (1998). $Mo$ data were collected from Abd-El Fatah (1996); Abd-El Wahed (1998); Hofstetter (2003) and the Harvard CMT catalogue. Within the magnitude range $1.7 \leq ML \leq 6.7$, we obtained two separate linear relations between $ML$ and $Mo$ (Fig. 12). The least square fitting gives the following equations:
\( (a-I) \quad 1.7 \leq M_L \leq 3.4 \)

\[ \log M_o = (1.0 \pm 0.05) M_L + (17.8 \pm 0.13) \]  
with \( N = 51, \) RMS = 0.16, R = 0.94 and \( P = 5.88\% \).

\( (a-II) \quad 3.5 \leq M_L \leq 6.7 \)

\[ \log M_o = (1.35 \pm 0.11) M_L + (16.3 \pm 0.53) \]  
with \( N = 118, \) RMS = 0.53, R = 0.74 and \( P = 2.54\% \).

The values of the coefficients inferred from these two separate relations are 1 and 1.35, respectively. Hanks and Boore (1984) reported that the linear approximation of the moment magnitude relation has not been well defined for \( M_L \geq 6.0 \). Considering this recommendation, we derived the \( M_L - M_o \) relation for the events with \( 3.7 \leq M_L < 6.0 \). Nevertheless we found negligible the change in the slope for the larger magnitudes, which indicates the applicability of extrapolation of the relation up to 6.7.

8. \( M_D(HLW) - M_o \) relation:

The linear relation between seismic moment and duration magnitude is shown in Figure (13). The best fitting for the magnitude range \( 2.4 \leq M_D(HLW) \leq 6.2 \) is as follows:

\[ \log M_o = (1.45 \pm 0.07) M_D(HLW) + (16.23 \pm 0.30) \]  
with \( N = 114, \) RMS = 0.52, R = 0.90 and \( P = 7.01\% \).

According to the obtained relations between the different pairs of magnitudes (Table 1), we observe that the relations between \( M_L - M_o \) (Fig.12), for the two different ranges of \( M_L \) magnitude, as well as \( M_D - M_o \) (Fig.13) exhibit a satisfactory correlation, with 2.54% to 7% of events falling outside two standard deviations from the regression line. According to the errors in the parameters A and B of the linear fitting (that represent the standard deviation of the estimated model parameters) and to the RMS values, the quality of the obtained regression for \( M_o \) can be ranked as follows: \( M_L \) (1.7 \( \leq M_L \leq 3.4 \)), \( M_D(HLW) \) and \( M_L \) (3.5 \( \leq M_L \leq 6.7 \)), as shown in Figures 12 and 13. The relations between \( M_D \) (HLW) and both \( M_L \) (IPRG) and \( m_b \) (ISC) (see Figures 7 and 9) provide a high correlation with 5.2% and 7% of the points that lie outside \( 2\sigma \) from the line, respectively. The standard deviation values for the parameters A and B of the fitted lines gives a good result, indicating that \( M_D \) (HLW) can be associated to \( M_L \) (IPRG) and \( m_b \) (ISC) with a smaller RMS value for \( M_D \) (HLW) – \( M_L \) (IPRG) relation. Considering the established relations between \( M_L \) (HLW) and both \( m_b \) (ISC) and \( M_L \) (IPRG), the \( M_L \) (HLW) can be associated to \( M_L \) (IPRG) as shown in Figure 10, while the statistics for \( M_L \) (HLW) – \( m_b \) (ISC) are very poor. The relation between \( M_L \) (HLW) – \( M_L \) (IPRG) magnitudes provides a correlation which is satisfactory, with about 3.77% of the points
outside $2\sigma$ and relatively small errors for the parameters A and B of the linear fitting. Although the $m_b - M_s$ relation (Fig.11) shows a high correlation, the standard deviation of the parameter B is significantly large; this means that this relation shows a weak correspondence for $m_b$.

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 $M_W$ as the size of as many of the earthquakes in the final catalogue of Egypt as possible, because $M_W$ is a parameter directly related to the source physics and it is expected to become increasingly available in the future. The moment magnitude $M_W$ can be derived from the scalar seismic moment $M_o$ (in Nm) using the relation of Kanamori (1977):

$$M_W = \frac{2}{3} \log M_o - 10.7 \quad (17)$$

In order to convert the different kinds of magnitude into moment magnitude, the best linear relations between different kinds of magnitude and the available magnitude types during the different periods are considered. For the time interval 1900-1984, the majority of earthquakes are generally quantified by $M(_{HLW})$ in addition to $m_b$. Therefore, we convert $M(_{HLW})$ to $m_b$ using the Maamoun et al. (1984) relation:

$$m_b = 0.97 \pm 0.05 M(_{HLW}) + 0.15 \pm 0.22 \quad (18)$$

with $N = 70$, RMS = 0.16, $R = 0.93$ and $P = 0\%$.

By using relation (8) we convert the $m_b$ values estimated from equation (18) into $M_D(_{HLW})$ and then we use equations (16) and (17) to convert $M_D(_{HLW})$ into moment magnitude. Since $M_{L(_{IPRG})}$ is more frequent than the other magnitudes in the period of time 1985-1997, the moment magnitude is calculated considering the $M_{L} - M_{o}$ relations (Equations (14), (15) and (17)). Since the catalogue of ENSN from 1998-2004 contains mainly $M_{L(_{HLW})}$ and considering the relations between $M_{L(_{IPRG})} - M_{L(_{HLW})}$ and also $M_{L} - M_{o}$ (Equations (12), (14) and (17)), we converted the different types of earthquake magnitudes into moment magnitudes for 9569 events within the whole period. The standard deviation of the difference between the moment estimated from our regression relationships and the moment calculated from Harvard CMT, waveform inversion and spectral analysis is 0.49. Translating this value into moment magnitude uncertainty, it corresponds to 0.3. In this work, we used the multi conversion scheme because the available data are inadequate to establish a robust straightforward relation between different magnitude types, such as the local magnitude, versus the moment magnitude $M_W$. This is due also to the fact that some magnitude data are only provided by local catalogues during a limited time period.
Completeness of the Catalogue

A preliminary analysis of the catalogue completeness, based on the estimated moment magnitude of the events, is performed for the time periods 1900-1984 (Maamoun et al., 1984 catalogue) and 1985-2004. The frequency-magnitude distributions, normalized by time, obtained for the two time intervals show that the unified catalogue can be considered rather complete for earthquakes having $M_W > 4.5$ during the first period and for $M_W > 3.0$ during the second time interval (Fig. 14). During the first period, only earthquakes with magnitudes $M(HLW) > 4.0$ can be converted to moment magnitude using the established relations. For the period 1985-2004 the catalogue includes all earthquakes with $M_{max} > 3$. By plotting the annual numbers of earthquakes of different $M_W$ magnitude ranges with time, we found a clear change at the year 1985 where the annual number of earthquakes smaller than 4 appears with a gradually increasing trend (Fig. 15). For magnitudes $4 \leq M_W < 5$ the annual number shows stability before 1969, whereas a number of peaks appear after 1969. These peaks represent the activity associated with the 1969, 1982, 1992, 1993 and 1995 earthquakes. For $M_W > 5$ the annual number is stable before 1992. The increasing trend that appears after 1992 is mainly related to the aftershocks of the 1993 and 1995 Gulf of Aqaba earthquakes.

For the time period 1900-1984 Maamoun et al. (1984) considered the magnitude threshold of completeness to be $M(HLW) \geq 3.6$ since the beginning of the WWSSN recording system (i.e. after 1962 and up to 1984) and $M(HLW) \geq 4.9$ before its operation. The analysis of ISC data for the considered region indicates a completeness threshold for $m_b$ (ISC) $\geq 5.0$ during the time interval 1900-2004 (Fig. 16a). On the other hand, the cumulative frequency magnitude relations, normalized by time, are considered for $M_D(HLW)$ and $M_L(HLW)$ for the time intervals 1985-1998 and 1998-2004, respectively (Figs. 16b and 16c). As a result, the catalogue is most likely complete only for these magnitude thresholds as follows: $M_D(HLW) \geq 3.9$ and $M_L(HLW) \geq 2$.

Discussion and Conclusions

We compile a unified earthquake catalogue of Egypt for the period 1900-2004, using all the national and international sources available to us. This study represents an extension and upgrading of the work published earlier by Maamoun et al. (1984). 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 (1900-1984). The location and magnitudes of moderate-large events in Egypt determined by the international seismological agencies were also reported in the Maamoun et al. (1984)
catalogue as they kept the locations of these agencies and listed all of the reported magnitudes.

Since 1985, a number of new seismological networks in the neighboring countries have been operated in addition to a large number of local stations, which increased the detectability of the small events throughout a short time period (13 years) from 1985 to 1997. Accordingly, the number of events increased from 371 in the first period of observation (1900-1984) to 5785 in the period from 1985 to 1997. This increase in activity is not only related to the continuing increase of recording stations but also to the high activity associated with swarms and aftershocks of some significant recent earthquakes (Cairo, 1992 and Aqaba 1993 & 1995). The ISC and PDE represent the main sources of the body wave ($m_b$) and surface wave ($M_S$) magnitudes values used in our analysis. The magnitudes included in the second period were local magnitude of IPRG ($M_L$), seismic moment ($M_o$), moment magnitude ($M_W$) and duration magnitude $M_D$ (HLW) of Helwan.

In the period from 1998 to 2004, the number of events increased rapidly. The reported numbers in this short period is 9719 events, which is nearly about 26.2 and 1.7 times higher than those counted in the first (1900-1984) and second (1985-1997) periods, respectively. This increase is due to the dense distribution of the seismic stations of ENSN. The magnitudes included in this period were the local magnitude $M_L$ of Helwan; in addition to the actually existing $m_b$ and $M_S$ of ISC and local magnitude of $M_L$(IPRG). Hence, the present catalogue comprises 15875 events, which occurred during the period 1900-2004.

Several linear relations have been derived by applying the least squares method, involving $m_b$(ISC)-$M_L$(IPRG), $m_b$(ISC)-$M_D$(HLW), $m_b$(ISC)-$M_L$(HLW), $M_L$(IPRG)-$M_D$(HLW), $M_L$(IPRG)-$M_L$(HLW) and $m_b$-$M_S$, for different magnitude ranges. The relations of log $M_o$ with $M_L$ and $M_D$ (HLW) have been derived as well. The values of the coefficients of the two separate relations of log $M_o$-$M_L$(IPRG) in the two ranges of 1.7≤$M_L$≤3.4 and 3.5≤$M_L$<6.0 are 1.0 and 1.35, respectively. This result shows a good agreement with that obtained, for California, by Ben-Zion and Zhu (2002) for the same magnitude ranges, as they concluded that the best fitting linear slope for $M_L$<3.5 events is ~1.0 while for $M_L$>3.5 events is ~1.34. The slope for $M_L$<3.5 events is also compatible with the result obtained by the proposed moment-magnitude relation of Dahshour area, Egypt (Abdelrahman et al., 2003) and the slope of the moment magnitude relation predicted by the theory of Kanamori and Anderson (1975) for very small earthquakes. On a global scale, the same value for this slope was estimated from the data set of large earthquakes ($M_S$ >6) containing the depth corrected $M_S$ (Romanelli and Panza, 1995). This might support the observation of Hanks and Boore (1984) that there is
no fundamental regional dependence in the moment-magnitude scaling relations. However, the slope values of the moment magnitude relations derived from the data set containing the depth corrected $M_S$ magnitude values for the different seismic zones and different depth intervals show that there are large variations, ranging from 1 to 2, for the large earthquakes (Romanelli and Panza, 1995).

In this work, we converted the various reported magnitudes into moment magnitude, using a multi-step approach. To do that, we chose the most frequently reported magnitude types that provide satisfactory regressions (i.e. that have good statistical parameters and low dispersion) with other magnitude types and with the seismic moment. This is the only possible solution to obtain a uniform magnitude type. However, the various reported magnitude types have been used in existing catalogues for a long time, because direct measurement of seismic moment became possible in the last few decades, only. The moment magnitude calculated from the other magnitude types may be considered complete for $M_W > 4.5$ during the period from 1900 until 1984 and for $M_W > 3.0$ during the recent period (1985-2004). The significant decrease in the threshold magnitude for the second period is mainly due to the increase of the number of seismological stations and improvements in the techniques of analysis.

Based upon the combined data set and taking into account the distribution of the number of earthquakes as a function of magnitude, different completeness levels for different magnitude types can be observed over the different time intervals of the catalogue. Considering the completeness thresholds $M_W = 4.5$ and $M_W = 3$ for the unified catalogue over the two different time intervals (1900-1984) and (1985-2004) respectively, we observe that the completeness level of the unified catalogue has been found to be higher than the completeness estimate for the ISC catalogue which gives a value of $m_b$ (ISC) $\geq$ 5.0 during 1900-2004. The completeness estimates for the reference magnitudes $M_D$(HLW) in the time interval 1985-1998 and $M_L$(HLW) $\geq$ 2 in the time interval 1998-2004 cannot be compared with the unified magnitude due to their limited time intervals.

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References


Primakov, I. and I. Rotwain, 2003: The package for analysis of earthquake catalogues (EDCAT, CATAL and AFT).Seventh Workshop on Non-Linear Dynamics and earthquakes Prediction, ICTP, Trieste, Italy


Sofratome Group; 1984: El-Dabaa nuclear power plant, NPPA, Ministry of Electricity, Egypt, unpublished report.
Table 1. A list of the regression relations parameters between different types of magnitudes.

<table>
<thead>
<tr>
<th>Relation</th>
<th>No. of events</th>
<th>a</th>
<th>S_a</th>
<th>b</th>
<th>S_b</th>
<th>RMS</th>
<th>R</th>
<th>P %</th>
</tr>
</thead>
<tbody>
<tr>
<td>M_L(IPRG) – m_b(ISC)</td>
<td>115</td>
<td>0.69</td>
<td>0.07</td>
<td>1.67</td>
<td>0.29</td>
<td>0.35</td>
<td>0.70</td>
<td>6.88</td>
</tr>
<tr>
<td>M_D(HLW) – m_b(ISC)</td>
<td>100</td>
<td>0.61</td>
<td>0.05</td>
<td>1.80</td>
<td>0.20</td>
<td>0.28</td>
<td>0.80</td>
<td>7.00</td>
</tr>
<tr>
<td>M_L(HLW) – m_b(ISC)</td>
<td>13</td>
<td>1.07</td>
<td>0.58</td>
<td>0.01</td>
<td>2.36</td>
<td>0.46</td>
<td>0.49</td>
<td>0.00</td>
</tr>
<tr>
<td>M_D(HLW) – M_L(IPRG)</td>
<td>423</td>
<td>0.60</td>
<td>0.02</td>
<td>1.47</td>
<td>0.07</td>
<td>0.24</td>
<td>0.82</td>
<td>5.20</td>
</tr>
<tr>
<td>M_L(HLW) – M_L(IPRG)</td>
<td>106</td>
<td>0.64</td>
<td>0.07</td>
<td>0.91</td>
<td>0.21</td>
<td>0.40</td>
<td>0.67</td>
<td>3.77</td>
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<tr>
<td>m_b – M_s</td>
<td>40</td>
<td>1.30</td>
<td>0.14</td>
<td>1.84</td>
<td>0.73</td>
<td>0.53</td>
<td>0.83</td>
<td>2.50</td>
</tr>
<tr>
<td>M_L ~ M_b</td>
<td>51</td>
<td>1.00</td>
<td>0.05</td>
<td>17.80</td>
<td>0.13</td>
<td>0.16</td>
<td>0.94</td>
<td>5.88</td>
</tr>
<tr>
<td>(1.7 ≤ M_L ≤ 3.4)</td>
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</tr>
<tr>
<td>M_L ~ M_b</td>
<td>118</td>
<td>1.35</td>
<td>0.11</td>
<td>16.30</td>
<td>0.53</td>
<td>0.53</td>
<td>0.74</td>
<td>2.54</td>
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<tr>
<td>(3.5 ≤ M_L ≤ 6.7)</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>M_D(HLW) ~ M_s</td>
<td>114</td>
<td>1.45</td>
<td>0.07</td>
<td>16.23</td>
<td>0.30</td>
<td>0.52</td>
<td>0.9</td>
<td>7.01</td>
</tr>
</tbody>
</table>

a, b: Coefficients of the fitting.
S_a, S_b: Standard errors of the coefficients.
R: Correlation coefficient.
RMS: Root mean square value.
P %: The percentage of points outside two standard deviations 2σ.
Figure 1. Tectonic boundaries and shallow seismicity pattern (h ≤ 60 km) of the Eastern Mediterranean Region (Abou Elenean and Hussein, 2007). A compiled tectonic elements after Sofratome Group (1984), Egyptian Geological Survey (1981) and Salamon et al. (1996). Seismicity data (mb ≥ 3) was compiled after: Riad and Meyers, 1985 from (1900-1964); ISC (1964-2005). Stress field directions are based on the stress tensor inversion after Christova and Nikolova (1994, Hellenic Arc) and Abou Elenean (1997, other localities). The following Acronyms present: AEG-Aegean Sea; CY-Cyprus; ERA-Eratosthenes Seamount; FL-Florence; IB-Ionian Basin; LEV-Levantine Basin; LF-Levant Fault; JAK-Jebel Al Akhdar.
Figure 2. Location of seismograph stations in Egypt up to 1994. Hexagonal present Helwan WWSSN station. Solid triangles present short period MEQ stations while open triangles present the stations of Hurghada telemetry seismic network (HSN). Solid squares present the stations of Aswan telemetry seismic network (ASN). Solid circles present Standard Russian World Wide Stations at Mersa-Matrouh (MAT), ASWAN, (ASW) and Abu-Simbel (ABS). Acronyms: AQ, Gulf of Aqaba; SC, Suez Canal; SZ, Gulf of Suez; CA, Cairo.
Figure 3. Geographic distribution of the Egyptian National Seismic Network (ENSN). Acronyms: AQ, Gulf of Aqaba; SC, Suez Canal; SZ, Gulf of Suez.
Figure 4. Seismicity of the study area during the period 1900-2004. Black lines are surface faults dotted where concealed.
Figure 5. Yearly number of events listed in the catalogue as a function of time and magnitude (period of time 1900-2004). I, II, III and IV represent the four time intervals of the activity.
Figure 6. Regression relations between $m_b$ and $M_L$(IPRG) for $3.8 \leq m_b \leq 6.1$.

Figure 7. Regression relations between $m_b$(ISC) and $M_D$(HLW), $3 \leq m_b \leq 6.1$. 
Figure 8. Comparison of $M_D$(HLW) estimated from Maamoun et al. (1984) relation and $M_D$(HLW) estimated by Equation (11), obtained in this study. The histogram shows the distribution of the estimated magnitude differences.

Figure 9. $M_L$(IPRG) versus $M_D$(HLW) regression relation.
Figure 10. $M_L$(HLW) versus $M_L$(IPRG) regression relation.

Figure 11. $m_b$ versus $M_S$ regression relation.
Figure 12. Least square fitting relations between seismic moment and local magnitude for $1.7 \leq M_L \leq 3.4$ & $3.5 \leq M_L \leq 6.7$.

Figure 13. Seismic Moment ($M_o$) versus $M_D$(HLW) regression relation.
Figure 14. Frequency-magnitude relations, normalized by time obtained for the moment magnitude $M_W$ for the two time intervals.
Figure 15. Yearly number of events listed in the catalogue as a function of time and moment magnitude (period of time 1900-2004).
Figure 16. Frequency-magnitude relations, normalized by time obtained for: a: $m_b$(ISC); b:$M_D$(HLW); c:$M_L$(HLW).