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A homogenous moment magnitude and local magnitude scaling relation for earthquakes in Egypt

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ABSTRACT

In this work, we publish a moment-local magnitude scale catalogue for the Egyptian National Seismic Network (ENSN) since 1997 to 2019 as necessary for the study of seismicity and seismic hazard estimation. Every year, the ENSN publish an annual bulletin of local and regional earthquakes recorded by the network with local magnitude (Ml) scale. The ENSN was recorded more than 36,730 approximately for local events since 1997. In this work, the Moment magnitudes (Mw) are computed for small earthquakes using a spectral analysis method, while the Moment magnitudes of moderate and large earthquakes are obtained using a complete waveform inversion and moment tensor techniques. An empirical relationship between moment magnitude (Mw) and local magnitude (Ml) of the earthquakes are developed using a linear regression. The Mw–Ml relationship used in this study was as follows:

Mw = 0.69 Ml + 0.58 for earthquakes with magnitude ≤3

Mw = 0.95 Ml – 0.15 for earthquakes with magnitude 3< ML≤6

The ENSN local magnitude (Ml) catalogue was converted to a moment magnitude (Mw) catalogue and attached as a supplementary material with this article for use by the researchers and authors in tectonic studies and seismic hazard evaluation of the region.

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Local magnitude; moment magnitude; spectral analysis; waveform inversion; Egyptian National Seismic Network (ENSN)

1. Introduction

The history of study of the magnitude of the earthquake began in 1935 with the scientist Richter (1935), where he was the first scientist to calculate the magnitude of the earthquake and developed the local magnitude scale (Ml). Then, over time, several other magnitude scales have been also developed to calculate the magnitude of the earthquake such as the surface wave magnitude (Ms) (Gutenberg 1945a), the body wave magnitude (Mb) (Gutenberg 1945b, 1945c), the duration magnitude (Md) (Herrmann 1975) and the moment magnitude (Mw) (Kanamori 1977; Hanks and Kanamori 1979) scales.

The civil engineers took information about earthquakes from seismologists after developed the seismic codes to use it for design buildings, tunnels, facilities and infrastructures to be more resistant to earthquakes in a certain region. Besides these earthquakes information, moment magnitude is essentially required from the global and local seismic networks to estimate this quantitative information. Prior to 2010, there are various studies have been published to make relationships between different magnitude scales and Helwan magnitude scale (ML) (e.g. Abdulrahman et al. 2003; Hussein et al. 2008). Hussein et al. (2008) used a multiple – conversion scheme and they utilised the wave inversion and spectral analysis results by the international earthquakes agencies such as ISC (International Seismological Centre) and Harvard CMT (Centroid Moment Tensor) catalogue. Indeed, one of the fundamental advantages of this study is the robust spectral inversion of high quality data after installing a number of broadband stations since 2010 in Egypt, which led to accurate determination of the seismic moment of local earthquakes and to establish a direct relationship between the local and moment magnitudes. Abdulrahman et al. (2003) derived a local-moment magnitude relation by the inversion of 55 records at only one broadband station. Their relation are only valid for Dahshour seismic zone and for a limited local magnitude range from 1.7 to 3.4. In the present work we used about 1240 earthquakes, and each event recorded at least by four broadband seismic station which led to accurate and reliable inversion results. The derived local-moment magnitude relation in this study is valid for all seismic zones in Egypt and for any local magnitude range.

Up to now, most of the seismic networks around the globe and also the ENSN still widely use the local magnitude scale to determine the magnitude of small and local earthquakes, which have epicenteral distance less than 400 kilometres. There are two major disadvantages of the Local Magnitude scale (Ml) proposed by Richter (1935) that prevents good use of it in evaluating seismic hazard studies. The first disadvantage is the saturation phenomenon for greater

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Supplemental data for this article can be accessed here.

magnitude events (Ml >6) the scale gets saturated (Hutton and Boore 1987). The second disadvantage of this scale is the negative values of some small earthquakes (e.g. the magnitude of some small earthquakes gives value less than zero). Therefore, the earthquake catalogue of the National Seismic Network (ENSN) suffered from these disadvantages.

The use of moment magnitude (Mw) scale (Kanamori 1977; Hanks and Kanamori 1979), is recommended in global or local networks (i.e. ENSN) to avoid the previous mention defects that exit in local magnitude scale (Ml).This type of magnitude scale is widely accepted and very important as a stable scale in conducting advanced studies to assess the seismic hazard and seismic code of any particular region (Hanks and Kanamori 1979; Howell 1981; Ottemoller and Havskov 2003).

Recently in Egypt, after up-grading the ENSN stations from short-period stations to broadband stations, some of the Egyptian researchers have been able to make the waveform inversion, spectral analysis and moment tensor solution to obtain the Moment Magnitude (Mw) of some earthquakes (Abd El-aal and Badreldin 2016; Abd El-aal and Yagi 2017; Abd El-aal et al. 2016; 2019; Badreldin et al. 2019; Hussein et al. 2013; Saadalla et al. 2019). In this work, an attempt has been made to link the Egyptian local magnitude scale (Ml) with the Moment Magnitude (Mw) through mathematical equations and we converted the Egyptian Ml magnitude catalogue to the Mw magnitude catalogue and attached it with this article in supplementary data.

2. The Egyptian National Seismic network (ENSN)

After the devastating earthquake that took place on 12 October 1992 near the Egyptian capital Cairo and the massive losses caused by the earthquake in human life, infrastructure and buildings, the Egyptian government decided to establish a national seismic network to monitoring, local and regional seismicity. The main purpose of this network is to reduce seismic hazard and risk by conducting valuable scientific studies and researches that provide future safe growth of huge strategic projects. The Egyptian government has entrusted the National Research Institute of Astronomy and Geophysics (NRIAG) with the establishment, installation and operation of the local seismic network.

Now, the ENSN seismic network includes about 31 broadband and 19 short- period stations distributed in the whole of Egypt equipped with sensors SS1, STS2, Trillium 40, 120 and 240 and L4 C model (Figure 1). The network also includes one main-centre located at Helwan town (Cairo city) and five sub-centres located at Aswan, Marsa Alam, Hurghada, Kharga, and Burg

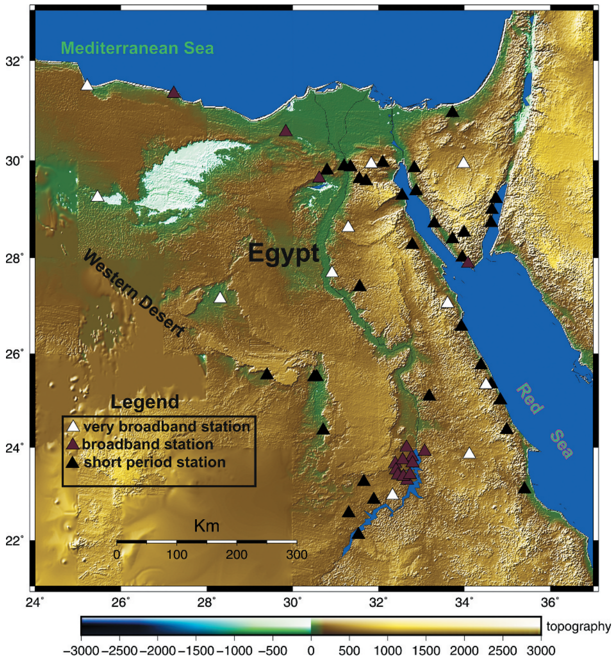

Figure 1. Map shows geographic distribution of the Egyptian National seismic Network (ENSN). White triangle refers to very broadband stations, the pink triangle represents the broadband stations, and black triangle shows short period stations.

El-Arab cities. The sub-centres are connected recently to the main centre using satellite communication. The digital seismic data is extracted from stations near the main-centre by radio and from remote stations through satellite using the Atlas software (www.nanometrics.com). The Atlas software is a friendly user interface programme with powerful tools for routine work is that used to extract the digital data of remote stations online from the ring buffer. The Atlas uses the HYPOINVERSE (Klein 1978, 1989), a location program was written and used by the United States Geological Survey (USGS) (www.usgs.gov), to locate earthquakes and calculate magnitudes. The Egyptian national seismological network covers all the Egyptian territory by different specific crustal models to locate the earthquakes accurately.

In ENSN, The seismologists staff are available 24 hours per day, in the case of an earthquake took place, the earthquake parameters (location, magnitude, etc) are extracted immediately manually and they disseminate these data through the internet on the Athena website of the ENSN. Annually, the Egyptian earthquake bulletin is produced and published on the local magnitude scale (Ml).

The ENSN collaborated with international seismological centres like seismological centre (ISC) (www.isc.ac.uk) and the Euro Mediterranean seismological centre (EMSC) (www.emsc-csem.org) in exchange information of earthquakes. For many reasons, the Egyptian ENSN is very important in North Africa because there are no global seismic stations in the region.

3. Catalogue data and magnitude scale

The annual earthquake bulletin is one of the products of the ENSN reports and lists all the recorded earthquakes in Egypt and the adjacent areas. The bulletin includes a list of local earthquakes and a list of regional earthquakes. Figure 2 shows the local seismicity of Egypt recorded by the National Seismic Network from 1997 to 2019. Approximately, more than 36,700 local earthquakes have been recorded with a local magnitude ranging from −0.8 to 6.1. There are two possibilities for interpreting zero-depth earthquakes in the ENSN network catalogue. The first explanation is artificial earthquakes caused by quarries for the manufacture of cement. The second explanation is a probable mistake in calculating the depth of the earthquake. Figure 3 illustrates some histograms of the catalogue's parameters.

The primary type of the magnitude of the earthquakes determined by Atlas program in the ENSN is the amplitude (Local) magnitude. The process for determining local magnitude (Ml) is modelled after the reading of maximum peak-to-peak amplitudes from the standard Wood-Anderson torsion seismograph. The ENSN is following User's Guide of the HYPOINVERSE program specifically regarding the correction of earthquake amplitude read from an electromagnetic sensor to equivalent Wood-Anderson response using Jerry Eaton's XMAG formulation (Eaton 1970, 1992). The ENSN uses the Richter's original formula:

$$M1 = \log(A) - \log(Ao) + S \quad (1)$$

where A is the measured maximum amplitude of recorded earthquake, Ao is the attenuation term

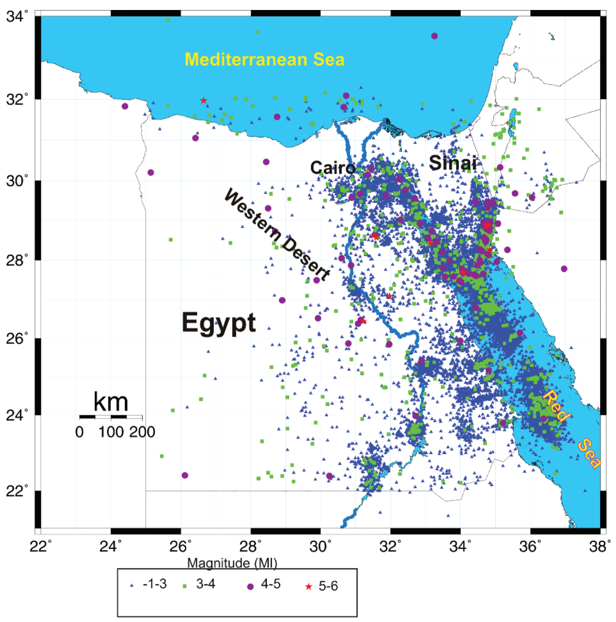

Figure 2. Map illustrates the local seismicity of Egypt recorded by the Egyptian ENSN network from 1997 – 2019.

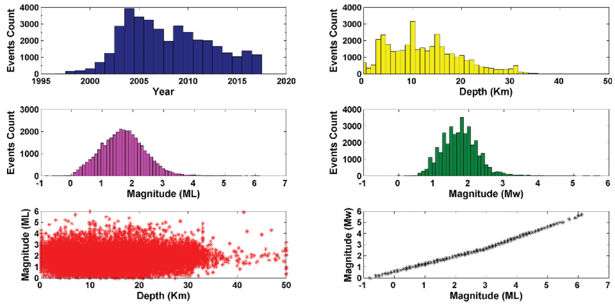

Figure 3. Histograms of the ENSN catalogue. The upper left panel shows a histogram between number of the earthquakes and recorded year. The upper right panel shows a histogram between the numbers of earthquakes and their depths. The middle left panel illustrates a histogram between numbers of the earthquakes and their Ml magnitudes. The middle right panel illustrates histogram numbers of the earthquakes and their Mw magnitudes. The lower left panel shows histogram between depth and magnitude. The lower right panel shows histogram between local magnitude and moment magnitude.

(reference event amplitude at specific distance) and S is station correction. Using Atlas software, Equation (1) can be written in the form:

$$Ml = \log(A_{WA}/2) - \log(Ao) \quad (2)$$

where A_{WA} is the maximum peak-to-peak amplitude in mm on the paper record, and log (Ao) is an attenuation term and is a tabulated function of distance. Therefore, the division by 2 is based on a reason of the peak-to-peak reading.

Jerry Eaton (1992), developed the "X" magnitude formula for velocity seismometers is used in HYPOINVERSE software. Basically, before the magnitude is calculated, the earthquake amplitude is converted to effective Wood-Anderson amplitude using the period at which the amplitude is measured and the response curve for the seismograph type. The equation is

$$MX = \log(A_{WA}/2 \text{ x } CAL \text{ x } R(f) \text{ x } S)) + F1(s) + F2(d) + XCORCOMP + XCORSTA \quad (3)$$

where: A_{WA} is peak-to-peak amplitude,

CAL is the dimensionless calibration factor,

R(f) is the frequency dependent response curve,

S is the seismometer motor constant in volt/cm/sec,

F1(s) and F2(d) are the log (Ao) distance correction,

XCORCOMP is the correction of all components and XCORSTA is the station correction.

Another type of magnitude scale used in the ENSN is the duration Magnitude scale (Md) and is used as a secondary option with the calculation of the magnitude of the earthquake from the local magnitude scale. Figure 4 shows the magnitude of completeness of ENSN, where the 1.6 value is the magnitude of

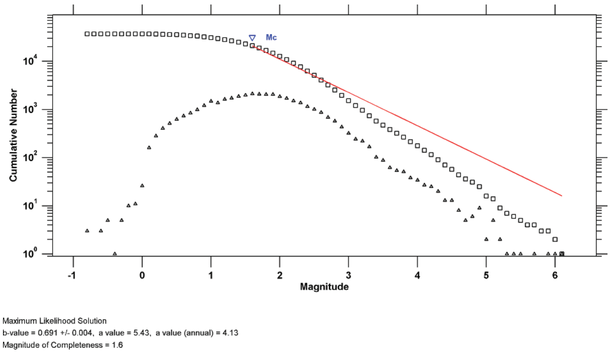

Figure 4. The magnitude of completeness curve. The a and b parameters are also given.

completeness for ENSN. Although the ENSN catalogue has negative values and magnitudes are smaller than the denominator 1.6 due to this denominator is a value for the entire ENSN network.

4. Methods

4.1. Spectral inversion

After upgrading the stations of the ENSN from short period band to broadband stations, the waveform inversion and moment tensor analysis have been increased to identify seismic moment and the moment magnitude (Mw) of small, moderate and large earthquakes with magnitudes greater than 3. Recently, a number of the Egyptian researchers (e.g. Abd El-aal and Badreldin 2016; Abd El-aal and Yagi 2017; Abd El-aal et al. 2016; 2019; Badreldin et al. 2019; Hussein et al. 2013; Saadalla et al. 2019), have conducted waveform inversion and spectral analysis to calculate Mw of local earthquakes recorded by the ENSN.

In this study, the Seismic Analysis Code (SAC) software are used to process the data (Figure 5). First the data are converted from SEED format to SAC format, and then the time windows are set for 1.28 s from P-wave arrival for Fast Fourier Transform (FFT), and the windows for noise prior to P-wave with the same times. As usual for FFT, the removal of the mean and linear trend, a 0.01 taper window are applied to the data point, zero padding and Parzen window of 5.0 Hz bandwidth are applied. The instrument response is corrected using the poles and zeros file of the stations. The observed displacement source spectra of P -wave obtained as mentioned above show good signal to noise ratio over the frequency range from 1 Hz to 50 Hz (Figure 6). The events that recorded in more than or equal to two seismic stations are involved in the inversion process. The Generalised Inversion Technique (GIT) using reference site was applied to separate the source spectra from both the site and path effects from the observed displacement P-wave spectra by iterative least square analysis (Iwata and Irikura 1988). The isolated displacement source spectra is modelled according to Brune (1970, 1971) and for small earthquakes assuming a circular fault as follows:

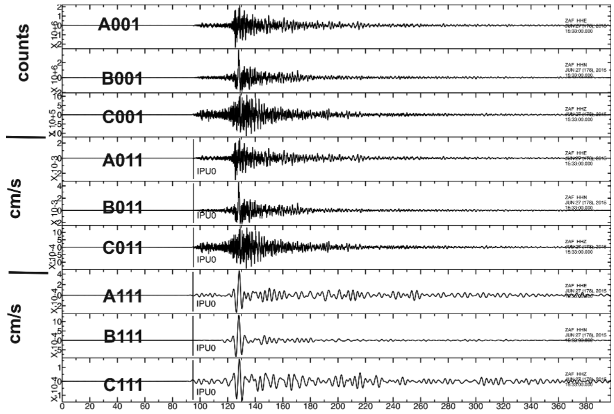

Figure 5. Example of the data processing steps of 17 June 2015 Aqpa earthquake with magnitude Ml 5.4. Panels (A1-C1), the observed velocity seismogram at Zafarana (ZAF) station. Panels (A2-C2), the corrected seismogram. Panels (A3-C3), the velocity seismogram after applying low pass filter.

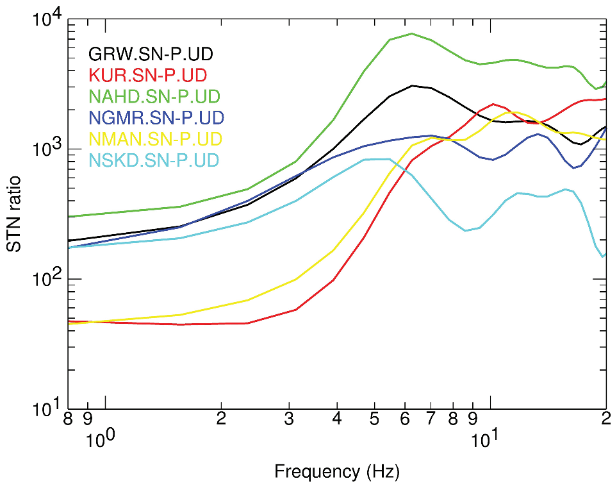

Figure 6. Example of Signal to Noise ratio (S/N) at each station recorded the 7 November 2010 earthquakes in Aswan region.

$$e_i(f) = \frac{\Omega_0}{1 + (f/f_c)^2}, \tag{4}$$

where Ω_0 is the long period asymptote, f_c the corner frequency. The relative moment for each displacement source spectra is determined from the mean amplitude in the frequency range from 6.25 Hz to 7.81 Hz to avoid the low signal to noise ratio at lower frequency. The formula used to calacualted the mean value of the relative seismic moment as follows:

$$\Omega_0 = \frac{(\Omega_{6.25} + \Omega_{7.03} + \Omega_{7.81})}{3} \tag{5}$$

Following Brune's (1970) relation, the seismic moment can be obtained from the P-wave displacement spectra:

$$M_0 = \frac{4\pi\rho(vp)^3 R\Omega_0}{FR_{\theta\varphi}} \tag{6}$$

where vp is velocity of P-wave, $\rho$is the density value, while R refers to the hypocentral distance. The $\Omega_o$refers to low frequency spectral amplitude, $R_{\theta\varphi}$ refers to a coefficient of the radiation pattern assumed equal to 0.52, and Frefers to the free surface effect, $(F = 2)$.

The moment magnitude Mw is directly obtained from seismic moment using the relation of Hanks and Kanamori (1979) as follow:

$$M_w = 2/3 log\, M_0 - 10.7 \tag{7}$$

Figure 7 illustrates an example of the calculation of source parameters, seismic moment and moment magnitude (Mw) for a small earthquake using spectral analysis technique. The spectral analysis technique in this research used to calculate Mw of the small earthquakes with magnitude values less than 3 recorded by the ENSN. While Figure 8 shows the process of calculating the moment magnitude (Mw) of a moderate earthquake from waveform inversion and moment tensor technique. Therefore, we now have a small catalogue of local earthquakes with moment magnitude (Mw) suitable to perform a relationship between local and moment magnitude scales.

4.2. Moment tensor analysis

In the light of this work, a full waveform moment tensor inversion method is applied based on algorithm in computer program in seismology (CPS.330) (Herrmann 2013). Assuming a point source, the ground displacement u in direction n at site x and time t can be equated as (Stump and Johnson 1977):

$$U_n(x,t) = M_{kj}\left[G_{nk,j} * s(t)\right], \tag{8}$$

where$M_{kj,}$ the moment tensor elements, $G_{nk,j}$the elastodynamic Green's function,and$s(t)$ the source time function. Assuming a synchronous source for all

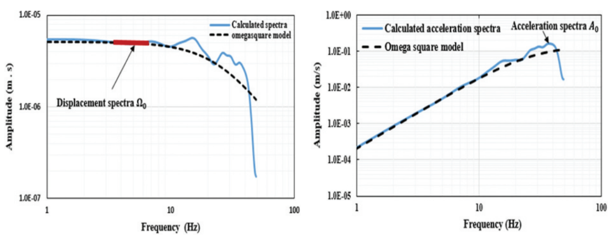

Figure 7. The left panel of the figure shows processing steps to obtain the displacement spectra of the 18 October 2014 (M_L3.1) earthquake at 10:55 UTC with depth 2 km, that took place in Aswan area. The right panel of the figure shows processing steps to acquire the acceleration spectra for the same event.

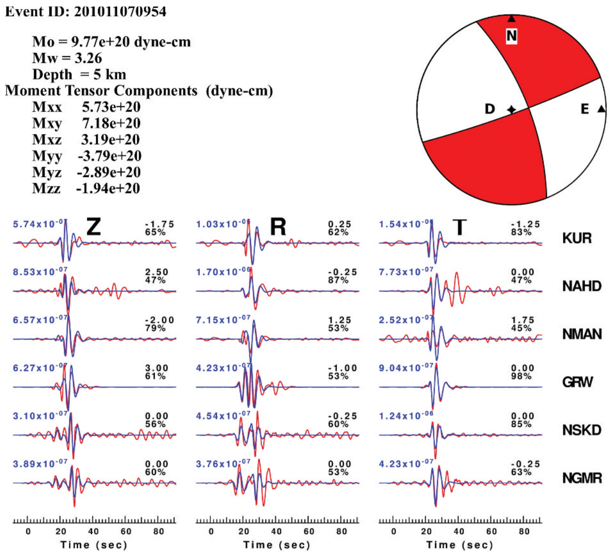

Figure 8. The figure shows processing steps using waveform inversion and moment tensor analysis to obtain the moment magnitude of the earthquake.

dependent moment tensor components and$s(t)$ is a delta function, Equation (8) can be formulated in linearised form in the frequency domain as,

$$U_n(f,x) = M_{kj}(f)G_{nk,j}(f), \tag{9}$$

This linearised form can be written in a matrix form as follow,

$$U = Gm \tag{10}$$

where u, the observed ground displacement, G is a matrix containing the Green's function computed using accurate velocity model, and m is the moment tensor elements. Inversion of Equation (10) to obtain the moment tensor elements is solved by a generalised least-squares method (Jost and Herrmann 1989).

5. Results

5.1. Local-moment magnitude relations

In order to carry out this work, we computed moment magnitude of 1242 earthquakes using waveform inversion and spectral analysis techniques as shown in Table 1 and we also collected moment magnitudes for 35 earthquakes from the previous works. Now we have a catalogue for some earthquakes that contains two magnitude scales Ml and Mw. For more realistic calculations, the catalogue has been divided into two sub-catalogues. The first sub-catalogue includes all earthquakes having magnitude values less than 3. The second sub-catalogue contains all the earthquakes with magnitude values greater than 3 and less than 6. A new MATLAB code has been written to carry out a linear regression fit between Ml and Mw scales with 95% confidence bounds and the following equations are devolved for the ENSN catalogue.

The obtained relations are as follows:

$$Mw = 0.69Ml + 0.58 \text{ for earthquakes with magnitude } \leq 3 \quad (11)$$

$$Mw = 0.95Ml - 0.15 \text{ for earthquakes with magnitude } 3ML \leq 6 \quad (12)$$

Figures 9 and 10 show the fitting curves of data, and the residuals. We tested and verified theses equations by comparing the Mw magnitude values of some earthquakes calculated by these new relationships and the Mw values calculated globally from the international seismic centres for the same earthquakes and we have found them to be quite identical. We have converted the ENSN catalogue from the local magnitude scale (Ml) to the moment magnitude scale (Mw) using the obtained equations and this catalogue had been attached with this research as a supplementary material for use by the scientists and researchers in advanced seismic hazard and risk assessment studies.

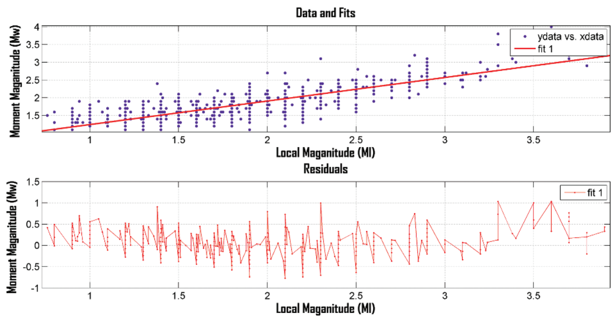

Figure 9. The fitting curve between local magnitude (Ml) and the Moment Magnitude (Mw) for earthquakes with magnitude values less 3. The residuals are also plotted in the bottom panel.

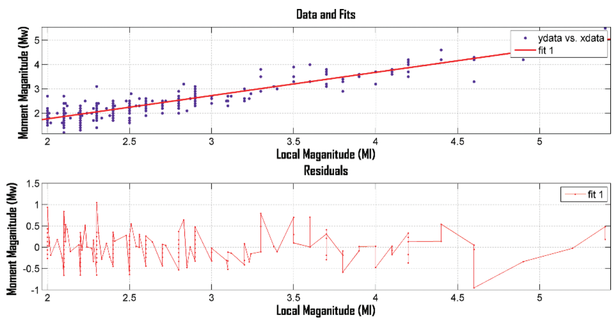

Figure 10. The fitting curve between local magnitude (Ml) and the Moment Magnitude (Mw) for earthquakes with magnitude values more than 3. The residuals are also plotted in the bottom panel.

6. Conclusion

This study is very useful for all the researchers and scientists who use the earthquake data of the Egyptian ENSN network. Indeed, this work sheds light on the earthquake catalogue recorded by the ENSN since its establishment. The study reveals that that the Egyptian ENSN recorded more than thirty seven thousand local earthquakes, in addition to large numbers of the regional earthquakes in the region, most of which were recorded in the Mediterranean Sea. However, this study included the local earthquakes only and did not take into consideration the regional earthquakes recorded by the ENSN. This because the regional earthquakes are far away from the monitoring stations which reveal high uncertainty in magnitude and location without including the international stations data. The study also shows that the Egyptian ENSN uses a local magnitude scale to measure the magnitude of the earthquakes. Furthermore, the study also clarifies that the network suffered from the disadvantages of this scale. For the above mentioned reasons, this study come to find a new relationship between local magnitude (Ml) scale and moment magnitude (Mw) scale. The Mw scale is very important which can be used in advanced studies on the assessment of seismic hazard for any region.

We introduce a relationship between the local magnitude and the moment magnitude scales from the ENSN local earthquakes catalogue from 2010 to 2017. The calculation of moment magnitudes has been done using spectral analysis and waveform inversion techniques. The moment magnitude is calculated for each displacement spectrum after removing the contributions of attenuation and sites effects. Basically, we have established two mathematical relationships between the local and moment magnitude scales according to the value of the magnitude of earthquake. Consequently, the developed relationships were tested and verified and we found that the calculated moment magnitude values from these equations corresponded perfectly to established moment magnitude values calculated from international seismic centres for same earthquakes.

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Disclosure statement

No potential conflict of interest was reported by the authors.

References

Abd El-aal AK, Badreldin H. 2016. Seismological aspects of the 27 June 2015 Gulf of Aqaba earthquake and its sequence of aftershocks. J Seismol. 20(3):935. doi:10.1007/s10950-016-9572-x.

Abd El-aal AK, Mostafa SI, Abdelhafiez HE. 2019. Review of the seismotectonic setting of the Gulf of Aqaba with respect to the 27 June 2015 and the 16 May 2016 earthquake sequences. Pure Appl Geophys. 176:541. doi:10.1007/s00024-018-2024-5.

Abd El-aal AK, Yagi Y. 2017. Earthquake source characterization, moment tensor solutions, and stress field of small—moderate earthquakes occurred in the Northern Red Sea triple junction. J Geosci. 21:235–251. doi:10.1007/s12303-016-0025-x.

Abd El-aal AK, Yagi Y, Kamal, Abdel-Rahman K. 2016. Implementation of integrated multi-channel analysis of surface waves and waveform inversion techniques for seismic hazard estimation. Arab J Geosci. 9:1–16. doi:10.1007/s12517-016-2329-6.

Abdulrahman EM, Dessoky MM, Hussein HH, Abd-El Wahed MF. 2003. Estimation of seismic moments from local magnitudes and coda durations for Cairo earthquake aftershocks recorded at Kottamiya (KEG) broadband station. Ann Geophys. 46(6):39–46.

Badreldin H, Abd El-aal AK, Toni M, El-Faragawy K. 2019. Moment tensor inversion of small-to-moderate size local earthquakes in Egypt. J Afr Earth Sci. 151:153–172. doi:10.1016/j.jafrearsci.2018.12.004.

Brune JN. 1970. Tectonic stress and the spectra of seismic shear waves from earthquakes. J Geophys Res. 75:4997–5009. doi:10.1029/JB075i026p04997.

Brune JN. 1971. Correction. J Geophys Res. 76:5002.

Eaton JP. 1970. Harmonic magnification of the complete telemetered seismic system, from seismometer to film viewer screen. U.S. Geological Survey Open-File Report. 23 pp.

Eaton JP. 1992. Determination of amplitude and duration magnitudes and site residuals from short-period seismographs in Northern California. Bull Seismol Soc Am. 82 (2):533–579.

Gutenberg B. 1945a. Amplitudes of surface waves and magnitudes of shallow earthquakes. Bull Seismol Soc Am. 35:57–69.

Gutenberg B. 1945b. Amplitudes of P, PP and S waves and magnitudes of shallow earthquakes. Bull Seismol Soc Am. 35:1–12.

Gutenberg B. 1945c. Magnitude determination of deep-focus earthquakes. Bull Seismol Soc Am. 35:117–130.

Hanks TC, Kanamori H. 1979. A moment magnitude scale. J Geophys Res. 84:2348–2350. doi:10.1029/JB084iB05p02348.

Herrmann RB. 1975. The use of duration as a measure of seismic moment and magnitude. Bull Seismol Soc Am. 65 (4):899–913.

Herrmann RB. 2013. Computer programs in seismology: an evolving tool for instruction and research. Seismol Res Lett. 84(6):1081–1088. doi:10.1785/0220110096.

Howell BF. 1981. On the saturation of earthquake magnitude. Bull Seismol Soc Am. 51:1013–1018.

Hussein HM, Abou Elenean KM, Marzouk IA, Peresan A, Korrat IM, Abu El-Nader E, Panza GF, El-Gabry MN. 2008. Integration and magnitude homogenization of the Egyptian earthquake catalogue. Nat Hazards. 47:525–546. doi:10.1007/s11069-008-9237-3.

Hussein HM, Elenean KA, Marzouk IA, Korrat IM, El-Nader IA, Ghazala H, ElGabry MN. 2013. Present-day tectonic stress regime in Egypt and surrounding area based on inversion of earthquake focal mechanisms. J Afr Earth Sci. 81:1–15. doi:10.1016/j.jafrearsci.2012.12.002.

Hutton LK, Boore DM. 1987. The ML scale in Southern California. Bull Seismol Soc Am. 77:2074–2094.

Iwata T, Irikura K. 1988. Source parameters of the 1983 Japan Sea earthquake sequence. J Phys Earth. 36 (4):155–184. doi:10.4294/jpe1952.36.155.

Jost ML, Herrmann RB. 1989. A student's guide to and review of moment tensor. Seismol Res Lett. 60(2):37–57. doi:10.1785/gssrl.60.2.37.

Kanamori H. 1977. Energy-release in great earthquakes. J Geophys Res. 82:2981–2987. doi:10.1029/Jb082i020p02981.

Klein FW. 1978. Hypocenter location program HYPOINVERSE. U.S. Geological Survey Open-File Report 78-694. 113 pp.

Klein FW 1989. HYPOINVERSE, a program for VAX computers to solve for earthquake locations and magnitudes. U.S. Geological Survey Open-File Report 89-314. 59 pp.

Ottemoller L, Havskov J. 2003. Moment magnitude determination for local and regional earthquakes based on source spectra. Bull Seismol Soc Am. 93:203–214. doi:10.1785/0120010220.

Richter CF. 1935. An instrumental earthquake magnitude scale. Bull Seismol Soc Am. 25:1–32.

Saadalla H, Abd El-aal AK, Mohamed A, El-Faragawy K. 2019. Determination of earthquake source parameters using the inversion of waveform data: A case of small earthquakes around High Dam Lake, Aswan region, Egypt. J Afr Earth Sci. 151:403–416. doi:10.1016/j.jafrearsci.2019.01.001.

Stump BW, Johnson LR. 1977. The determination of source properties by the linear inversion of seismograms. Bull Seismol Soc Am. 67(6):1489–1502.