American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-10, Issue-6, pp-85-95
www.ajer.org
Research Paper Open Access

Preliminary Scaling Relations of Moment Magnitude With Local Magnitude And Seismic Moment, For Albania

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ABSTRACT: *In this study, we determine preliminary scaling relations between moment magnitude (M_W) and local magnitude (M_L). Scaling is attempt for practical routine, also between local magnitude (M_L) and seismic moment, for Albania. Models are fitted based on parametric data of 110 moderate to strong earthquakes, recorded from the Albanian Broadband Seismic Network (ASN-BB), during the last decade. Part of the data involved is already processed and published by authors, applying spectral analysis, and improved recently by the last seismic activity in Albania. Analysis include the deadly and devastating earthquake of November 26, 2019 (M_W 6.4), that hit the west coast of Albania at the Eurasia-Adria collision tectonic contact. Mostly M_W is estimate to lower magnitude earthquakes, using spectral analysis of S-waves, from horizontal component seismograms, although estimations based on moment tensor inversion (MT), is considered for some of the earthquakes. The M_L-M_0 relationship is investigated in details by orthogonal regression analysis. Moreover, the M_W-M_L scaling is also determined, extending for earthquakes with within 3.0 – 6.4 magnitude values, as a local and straightforward practical relation for Albania. Investigated scaling relations comply well with similar ones in other regions in the world showing same seism-tectonic pattern.*

Date of Submission: 25-05-2021 Date of acceptance: 07-06-2021

I. INTRODUCTION

Earthquakes can be quantified in terms of energy release, which is related to the fault dimensions, slip, and stress drop (Ottemöller, L., Havskov, J., 2003). The earthquake magnitude is regarded as the most directly measurable and simple parameter to quantify the size of an earthquake, being as such the most common relative measure for the seismic ground motion (Bora, 2016). The last depends on the size of the corresponding earthquake (Margaris and Papazachos, 1999). The seismic waves radiated from the source, are made up of a wide spectrum of frequencies and measured by different instruments, providing views into different frequency ranges of radiated seismic energy (Margaris and Papazachos, 1999). Due to this fact, the size of any earthquake, can be measured by many magnitude scales. Nevertheless, the Richter local magnitude M_L (Richter, 1935) (Stein & Wysseison, 2003), scale is still widely used. Its importance rely on the representative frequency band, as assumed by definition, corresponding to the response frequency for the majority of common built structures, as the result of seismic action. Thus, M_L is directly related to the near field damage caused by an earthquake (Stein, S., Wysession, M., 2009). Beside M_L, the most commonly used magnitudes, especially as the primary application of earthquake size quantification for engineering design, are the surface wave magnitude M_S (Gutenberg, 1945; Margaris and Papazachos, 1999; Bormann, 2012) and the moment magnitude M_W (Hanks and Kanamori, 1979).

The moment magnitude scale (Mw), defined by (Kanamori, 1977), has the advantage of not saturating for the largest earthquakes, unlike the amplitude-based scales (Hanks and Kanamori, 1979; Ottemöller, L., Havskov, J., 2003). The ground movement at a given location depends on the radiation pattern, propagation along the travel path, and local site conditions. The moment magnitude (M_W), is developed to quantify the size of earthquakes, averaging over the effects of geometric spreading and attenuation (Kanamori, 1983; Ottemöller, L., Havskov, J., 2003). M_W is defined based on the seismic moment M_0 (Hanks and Kanamori 1979; Howell 1981; Ottemöller and Havskov 2003). The seismic moment M_0 is proportional to the far-field static-strain field (Aki, 1967; BenMenahem et al. 1969), thus is considered as a new parameter to specify the size of an earthquake. Most seismologists agree that M_W, based on a physical quantity and is non-saturating for great earthquakes, should be the prime magnitude scale. This enables the wide acceptance of M_W as a stable scale, for larger as well as small to moderate magnitude earthquakes (Lay and Wallace 1995). However, the more traditional amplitude-based scales are still more common and at least provide historic continuity (Miyamura, 1982; Ottemöller, L., Havskov, J., 2003).

Local magnitude M_L is routinely determined, for earthquakes in and nearby Albania, since the start of the seismic monitoring service (Muço, 1978). A more refined and well calibrated M_L scale, was introduced after 90-s, and new relations were developed to be used within the region instrumentally covered by the Albanian Seismic Network (ASN), based on the analogous instrumental recordings (Muço and Minga, 1992; Muço et al, 2002). For more than three decades it was difficult to introduce waveform data analysis due to the lack of modern digital instrumentation (Muço et al, 2002; Dushi et al, 2017). As the Albanian catalogue is characterized mainly by small to moderate earthquakes ($M_L \leq 3.0$), the Biswas and Aki (1984) approach was used to derive the first representative moment magnitude scale (M_W) for ASN (Muço et al, 2002). During the period of digital seismic instrumentation in Albania, starting on 2002 by operating short period (SP) stations equipped with 0.2 sec geophones and 16 bit recorders, few moderate earthquakes have been recorded. Ultimately, after a decade of operation of broadband seismic stations by ASN, and the advent of the strong Durresi Earthquake (M_W6.4), that hit the western coastal region of Albania on November 26, 2019, sufficient data has been gathered to attempt a preliminary scaling relation between the spectral parameter M_0 and its corresponding magnitude M_W, with local magnitude M_L, mainly intended for practical routine bases of everyday earthquake monitoring by ASN. The aim is to make use of the appropriate digital seismic data, recorded by the Albanian Broadband Seismic Network (ASN-BB), for fast and reliable determination of the main source parameters and the corresponding $M_{W,}$ based on preliminary calibrated empirical relations for Albania.

II. DATA SOURCES

We have investigated source parameters of 110 moderate to strong earthquakes ($2.0 \leq M_W \leq 6.4$), occurred in Albania during the last decade, which correspond also to the operation of the Albanian broadband, digital Seismic Network (ASN-BB), making possible a preliminary analysis. Selected data are constrained by the nature of the Albanian seismicity, which is caused mainly due to the continental collision between Adria microplate and western margin of the Eurasian plate. Thus, it is mainly characterized by shallow, small and moderate earthquakes. Although well-evidenced, the strong earthquakes have occurred in the past, and recent seismic activity has been generally moderate (Rama & Dushi, Apparent stress determination from radiated seismic energy and seismic moment of small and moderate earthquakes in Albania, 2019). Spatial distributions of earthquakes coincide with main active faults in Albanian. M_W and relevant source parameters of earthquakes in Albania, has been evaluated before based on empirical relations, while spectrally determined recently based on broadband seismic spectra, in frequency domain (Rama & Dushi, Source scaling relations of small to moderate Earthquakes in Albania, 2017).

Earthquakes data used in this work consist of waveforms recorded by the Albanian Broadband Seismological Network (ASN-BB). Presented waveform data are recordings of digital broadband (BB) seismic stations, equipped with 40 sec active sensors and 24 bit dataloggers. Recordings are sampled at 100 sps. A map showing the distribution of ASN-BB seismic stations along with earthquakes used in this study is shown in figure 1. Broadband seismological stations of ASN-BB, in operation since 2006, are located in different rocky sites insure a good signal to noise ratio (SNR). They are situated in B. Curri (BCI), Peshkopia (PHP), Puka (PUK), Shkodra (SDA) in the northern Albania; Korça (KBN), Vlora (VLO), Saranda (SRN) and Leskoviku (LSK), in southern Albania. The central ASN station, which is also a standardized Euro-Mediterranean Seismic Network (MedNet) station, situated in Tirana (TIR), is currently differing as equipped with a STS-2 (120 sec) sensor.

More than 100 moderate to strong earthquakes recorded along a 10 years period 2008-2019, are shown on the corresponding map (Fig. 1). There is no distinction between foreshocks, main shocks and aftershocks, which are all included and analyzed. A constraint is posed for all the events ($M_W \geq 2.6$), to be recorded by more than 5, 3-C stations, sake of accuracy. The events used are mainly shallow, being located at the depths ≤ 40 km, thus mostly above the Moho (assumed 30 km). Only in separate cases, earthquakes with depths more than 30 km are considered in this case.

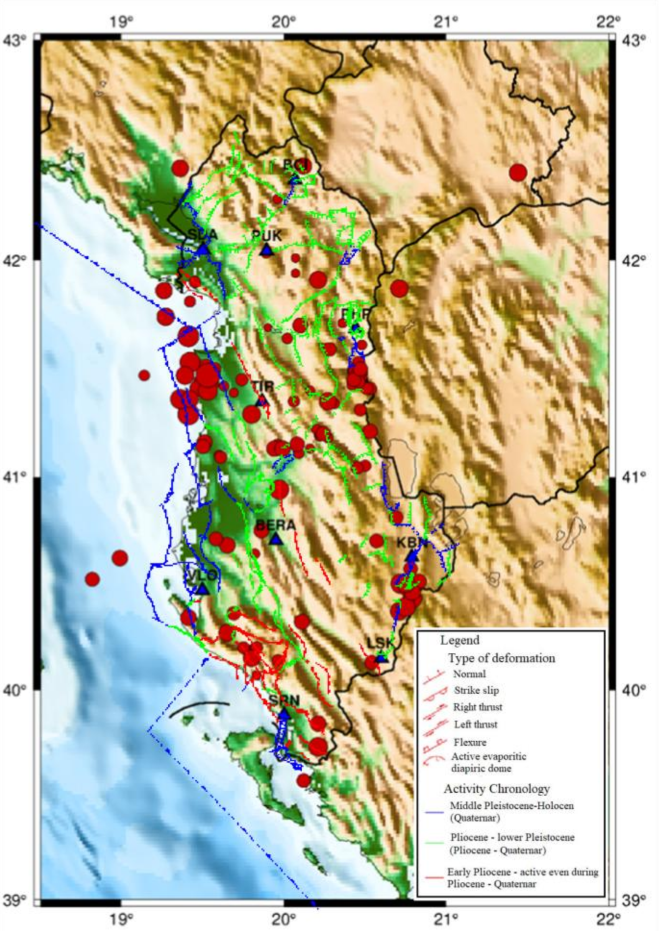


Figure 1. Albanian Broadband Seismic Network (ASN-BB) and the distribution of earthquakes used in this study.

The average hypocenter depth is 10 km, which results the common seismic depth for the Albanian crust. Corresponding parametric data are given in table 1.

Table 1*-Parametric data, from moderate to strong Earthquakes, considered in the study.*

No.	Date	Time	Lat.	Lon.	Dep.	Mag.	Mag	M_0	Source
	mm/dd/yyyy	*hh:mm*	*N-S*	*E-W*	*km*	*M_w*	*Ml*	*Nm*	
1	2/6/2008	0:52	41.42	19.63	5	2.6	3.6	1.00E+13	Spec. Analysis
2	3/5/2008	4:08	40.18	19.8	0	3.7	4.2	4.00E+14	Spec. Analysis
3	3/5/2008	6:48	40.2	19.83	5	3.2	3.4	6.30E+13	Spec. Analysis
4	3/6/2008	6:46	40.2	19.75	5	3.1	3.2	5.00E+13	Spec. Analysis
5	3/31/2008	8:06	41.13	20.16	0	2.5	3.1	7.90E+12	Spec. Analysis
6	4/8/2008	7:37	40.14	19.96	3	3	3.3	4.00E+13	Spec. Analysis
7	5/14/2008	19:17	41.34	20.31	0	2.8	3.5	2.00E+13	Spec. Analysis
8	5/15/2008	23:52	41.39	19.69	12	2.4	3.4	5.00E+12	Spec. Analysis
9	5/18/2008	22:49	41.9	19.45	11	3	3.2	4.00E+13	Spec. Analysis
10	5/21/2008	19:04	41.11	20.09	6	2.9	3.4	3.20E+13	Spec. Analysis
11	5/27/2008	0:44	42.03	19.89	39	2.4	2.9	5.00E+12	Spec. Analysis
12	5/29/2008	13:39	42.28	19.96	15	2.6	2.7	1.00E+13	Spec. Analysis
13	5/30/2008	20:40	41.71	20.36	0	2.4	2.7	4.00E+12	Spec. Analysis
14	5/31/2008	11:42	41.64	20.02	16	2.8	3	2.50E+13	Spec. Analysis
15	6/2/2008	8:05	41.61	20.48	5	2.6	3.4	7.90E+12	Spec. Analysis
16	6/25/2008	18:05	41.42	19.49	31	3.4	3.8	1.30E+14	Spec. Analysis
17	1/8/2009	12:04	41.87	20.71	0	4.6	5.1	1.00E+16	Spec. Analysis

18	1/31/2009	12:19	40.36	19.69	0	3.5	3.4	2.00E+14	Spec. Analysis
19	2/28/2009	17:36	41.5	19.57	5	3.5	3.5	2.50E+14	Spec. Analysis
20	3/7/2009	18:51	41.16	19.51	4	4	4.4	1.30E+15	Spec. Analysis
21	3/9/2009	0:30	41.94	20.07	20	2.3	3	4.00E+12	Spec. Analysis
22	3/10/2009	8:32	41.21	20.53	5	3.9	3.9	7.90E+14	Spec. Analysis
23	3/10/2009	22:30	41.31	20.47	5	3.2	2.4	7.90E+13	Spec. Analysis
24	3/11/2009	2:48	40.52	18.82	15	3.7	4.3	5.00E+14	Spec. Analysis
25	3/12/2009	18:55	41.35	20.06	15	3	3.2	4.00E+13	Spec. Analysis
26	3/18/2009	16:20	41.14	19.96	12	3.8	4	6.30E+14	Spec. Analysis
27	3/25/2009	12:23	40.62	18.99	16	4.1	3.9	2.00E+15	Spec. Analysis
28	3/30/2009	19:48	41.1	19.6	6	2.6	2.8	1.00E+13	Spec. Analysis
29	4/2/2009	5:45	41.09	19.61	15	3.2	3.2	7.90E+13	Spec. Analysis
30	4/6/2009	0:31	41.47	19.14	16	2.8	2.6	2.00E+13	Spec. Analysis
31	4/7/2009	13:49	41.44	19.48	20	3.2	3.2	7.90E+13	Spec. Analysis
32	4/7/2009	16:00	41.43	19.57	25	2.5	3.2	7.90E+12	Spec. Analysis
33	5/21/2009	12:11	41.05	20.5	6	3	3.2	4.00E+13	Spec. Analysis
34	5/21/2009	13:26	41.04	20.45	13	3.3	3.4	1.30E+14	Spec. Analysis
35	6/4/2009	22:36	40.07	19.83	6	2.5	3.2	7.90E+12	Spec. Analysis
36	6/12/2009	10:12	42.01	20.07	26	2.3	-	3.20E+12	Spec. Analysis
37	6/14/2009	5:12	41.45	19.74	15	3.2	3.2	6.30E+13	Spec. Analysis
38	6/20/2009	10:21	41.21	20.24	5	2.6	3.1	1.00E+13	Spec. Analysis
39	6/20/2009	17:00	41.19	20.22	6	2.9	3.1	2.50E+13	Spec. Analysis
40	6/21/2009	6:07	41.4	20.16	0	2.5	2.7	6.30E+12	Spec. Analysis
41	6/21/2009	17:35	41.2	20.22	10	2.8	3.2	2.00E+13	Spec. Analysis
42	6/21/2009	19:05	41.22	20.2	10	2.6	3.5	1.00E+13	Spec. Analysis
43	6/24/2009	2:24	41.69	19.9	5	2	2.4	1.30E+12	Spec. Analysis
44	6/24/2009	3:28	41.81	19.42	6	2.9	3.3	2.50E+13	Spec. Analysis
45	6/27/2009	0:45	41.18	20.27	3	2.7	3.4	1.30E+13	Spec. Analysis
46	6/27/2009	23:24	40.64	19.82	4	2.6	3	7.90E+12	Spec. Analysis
47	9/6/2009	21:49	41.49	20.45	8	5.2	5.4	7.90E+16	Spec. Analysis
48	9/6/2009	22:01	41.48	20.47	16	3.8	3.6	6.30E+14	Spec. Analysis
49	9/6/2009	22:24	41.59	20.28	0	3.5	3	2.50E+14	Spec. Analysis
50	9/6/2009	22:36	41.41	20.53	10	3.3	3.9	1.00E+14	Spec. Analysis
51	9/6/2009	23:31	41.53	20.46	6	3.2	3.3	7.90E+13	Spec. Analysis
52	9/7/2009	0:11	41.46	20.47	15	3.4	3.8	1.60E+14	Spec. Analysis
53	9/7/2009	3:52	41.47	20.46	15	3.1	3.3	5.00E+13	Spec. Analysis
54	9/7/2009	4:03	41.49	20.46	20	3.1	3	5.00E+13	Spec. Analysis
55	9/7/2009	4:22	41.41	20.51	17	3.2	2.9	7.90E+13	Spec. Analysis
56	9/7/2009	9:48	41.43	20.43	13	3.8	3.5	6.30E+14	Spec. Analysis
57	9/7/2009	12:21	41.47	20.45	12	3.3	3.4	1.00E+14	Spec. Analysis
58	9/7/2009	13:04	41.49	20.43	10	3	3.1	4.00E+13	Spec. Analysis
59	9/7/2009	13:42	41.47	20.44	20	3.4	3.3	1.60E+14	Spec. Analysis
60	9/7/2009	14:19	41.44	20.46	15	3.4	3.3	1.30E+14	Spec. Analysis
61	9/7/2009	15:20	41.45	20.43	5	3.7	4.2	4.00E+14	Spec. Analysis
62	9/13/2009	14:03	39.57	20.12	41	3.5	3.3	2.50E+14	Spec. Analysis
63	9/15/2009	8:37	41.14	19.5	5	3.8	4.3	6.30E+14	Spec. Analysis
64	9/17/2009	22:53	39.84	20.21	5	4.1	3	2.00E+15	Spec. Analysis
65	11/11/2009	3:43	40.32	20.11	0	4	4.1	1.30E+15	Spec. Analysis
66	5/6/2010	13:06	41.2	20.24	1	3.8	4	6.30E+14	Spec. Analysis
67	10/11/2010	0:34	42.4	21.44	6	4.6	5.2	1.00E+16	Spec. Analysis
68	5/5/2012	15:55	40.15	19.8	5	4.4	4.2	5.00E+15	Spec. Analysis
69	9/4/2012	22:43	41.13	19.94	3	4.1	4	1.60E+15	Spec. Analysis
70	11/26/2012	22:05	41.7	20.1	1	4	4	1.30E+15	Spec. Analysis
71	11/27/2012	19:06	40.75	19.86	5	4	4.1	1.00E+15	Spec. Analysis
72	11/28/2012	1:49	42.43	20.12	6	4.3	4.3	3.20E+15	Spec. Analysis

73	12/13/2012	21:39	41.13	19.99	6	4.2	4	2.50E+15	Spec. Analysis
74	6/22/2013	8:41	40.27	19.65	16	4.4	4.5	5.00E+15	Spec. Analysis
75	6/30/2013	2:47	41.5	20.47	17	3.8	3	5.00E+14	Spec. Analysis
76	8/4/2013	23:45	40.13	20.54	0	3.7	3	4.00E+14	Spec. Analysis
77	8/15/2013	15:49	40.57	20.78	5	3.6	3	3.20E+14	Spec. Analysis
78	11/21/2013	19:45	40.68	19.65	4	4.2	4	2.50E+15	Spec. Analysis
79	1/17/2014	19:42	40.81	20.69	5	3.6	3	3.20E+14	Spec. Analysis
80	1/20/2014	6:00	41.41	19.47	9	4.3	4.5	3.20E+15	Spec. Analysis
81	3/8/2014	15:12	41.51	19.52	10	4.1	4.2	1.60E+15	Spec. Analysis
82	4/6/2014	12:56	40.71	19.58	4	3.7	3.1	4.00E+14	Spec. Analysis
83	4/21/2014	21:25	41.86	19.26	5	4.3	4.5	3.20E+15	Spec. Analysis
84	5/12/2014	0:54	39.73	20.21	16	4.9	5.1	3.20E+16	Spec. Analysis
85	5/19/2014	0:59	40.94	19.97	1	5	4.6	4.00E+16	Spec. Analysis
86	12/29/2014	20:34	41.74	19.27	6	4.6	4.5	1.00E+16	Spec. Analysis
87	1/24/2015	17:01	40.7	20.57	5	3.6	3.2	3.20E+14	Spec. Analysis
88	2/7/2015	1:56	41.91	20.21	5	4.5	4.8	6.30E+15	Spec. Analysis
89	2/16/2015	20:23	41.15	20.08	0	3.9	4	1.00E+15	Spec. Analysis
90	2/28/2015	17:07	41.35	20.28	8	3.7	3.2	4.00E+14	Spec. Analysis
91	7/6/2015	13:42	42.42	19.36	6	4.4	4.1	5.00E+15	Spec. Analysis
92	11/1/2015	6:26	41.35	20.27	0	4.6	4.8	7.90E+15	Spec. Analysis
93	7/4/2018	9:01	41.4	19.53	24	5.1	5.1	6.30E+16	Spec. Analysis
94	6/1/2019	4:26	40.5	20.72	11.5	5.2	5.1	8.30E+16	Spec. Analysis
95	6/1/2019	4:33	40.43	20.79	15.5	4.9	5	3.08E+16	Spec. Analysis
96	6/1/2019	4:52	40.37	20.71	13.5	4.7	4.8	1.30E+16	MT – EMSC
97	6/1/2019	7:00	40.39	20.75	11.5	5	4.7	4.40E+16	Spec. Analysis
98	6/1/2019	9:11	40.48	20.75	6	3.9	3.9	9.00E+14	MT – EMSC
99	6/1/2019	15:19	40.51	20.83	6	4	4	1.20E+15	MT – EMSC
100	6/1/2019	18:50	40.46	20.79	18	4.3	4.4	3.47E+15	MT – EMSC
101	9/21/2019	14:04	41.29	19.41	17.5	5.6	5.8	3.69E+17	Spec. Analysis
102	9/21/2019	14:15	41.36	19.36	19	5.1	5.3	6.50E+16	Spec. Analysis
103	9/21/2019	16:10	40.34	19.41	35	4.2	4.2	2.45E+15	MT – EMSC
104	9/21/2019	22:07	41.36	19.42	10	4.4	4.6	4.90E+15	MT – EMSC
105	11/1/2019	5:25	40.5	20.75	9	4.7	5.3	1.38E+16	MT – EMSC
106	11/26/2019	2:54	41.47	19.53	19.5	6.4	6.3	4.56E+18	MT – EMSC
107	11/26/2019	6:08	41.65	19.41	21.5	5.5	5.5	2.32E+17	Spec. Analysis
108	11/26/2019	13:05	41.29	19.8	23.5	4.7	4.9	1.26E+16	MT – EMSC
109	11/27/2019	14:45	41.53	19.42	19.7	5.3	5.4	1.20E+17	Spec. Analysis
110	11/28/2019	10:52	41.47	19.39	20	4.7	5	1.40E+16	MT – EMSC

III. METHOD USED

The used method consists in spectral analysis on corrected displacement spectra of recorded waveforms, from moderate earthquakes, obtaining the seismic moment M_0 [Nm]. While, seismic moment for larger events is included from reported values by different regional and international seismological agencies, based on the well-known moment tensor inversion (MT). Most earthquake source theories predict a far-field displacement spectrum that is constant at low frequencies and inversely proportional to some power of frequency at high frequencies (Haskel 1964; Savage 1966; Aki 1967; Brune 1970; Molnar et al. 1973). From a body wave spectra two quantities are obtained, the long-period spectral level, $\boldsymbol{\Omega_0}$, and the corner frequency, $\boldsymbol{f_c}$.

Since the data utilized in this study correspond mainly to moderate earthquakes, based on the source location from Hypocenter program in SEISAN (ver. 11) system (Ottemöller, Voss, & and Havskov, 2020), the SPEC program on recorded S-wave packets is used. Spectra is obtained for rotated horizontal components through the Fast Fourier Transform (FFT) analysis. This is done for all stations associated to each event. The well-known Brune (Brune, 1970) model, assuming a circular source model, is applied. This approximation considers the earthquake sources as a point sources, within a half-space earth volume. Accuracy of the displacement source spectra is assured through the spectral correction on the radial and transversal components. Correction in spectral domain is crucial on the local, high frequency signals, of small to moderate earthquakes. It accounts for source, path and instrumentation effects. A base-line correction is applied as well, by removing the DC level, through a 10% sine taper, on each end of the selected signal's portion. Applying this procedure, we have obtained corrected, near field displacement spectra, upon which the theoretical Brune source model is applied, in the form (1).

$$\mathbf{S}(f) = (2.0)(0.6)\mathbf{G}(\Delta,\, h)\mathbf{D}(f)\mathbf{M_0}[(4\pi\rho v^3{}_S)\ (1+f^2/f^2{}_C)]^{-1} \qquad (1)$$

Model (1) is both visually and/or automatically fitted to the observed data. This is controlled by well constrained and pre-defined control parameters. In (1), **G**(Δ, h) defines the geometrical spreading factor, as the function of both epicenter distance and hypocentral depth, respectively Δ (km) and h(km); **D**(f) is the diminution function taking into account the intrinsic anelastic attenuation; f and f_c, corresponds to the spectral and source corner frequencies; ρ (kg/cm3) and v (km/s) are the density and wave velocity (S-wave) at the source volume, equaling 2.75 kg/cm^3 and 3.65 km/s, respectively; We have applied theoretical factors 2.0 and 0.6 to account for free surface and the radiation pattern effects, considering the body waves group.

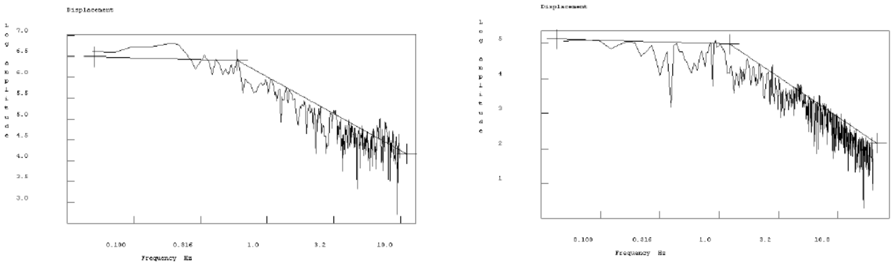


Figure 2. Corrected displacement spectra of September 6, 2009 (M_W =5.4) earthquake, computed using equation (2), respectively for TIR and BCI stations (Rama & Dushi, Apparent stress determination from radiated seismic energy and seismic moment of small and moderate earthquakes in Albania, 2019)**.**

The most crucial problem was to correct for the path effect (attenuation), through an appropriate diminution function **D**(f). We have considered the form (2), for this function.

$$\mathbf{D}(f) = \mathbf{P}(f)e^{-\pi f\tau}[\mathbf{Q}_0 f^{\alpha}]^{-1} \qquad (2)$$

In (2), **P**(f) is the function accounting for near surface losses. This function has the form **P**(f) = $e^{-\pi\kappa f}$. Here **κ -** factor is a local characteristic quantifying the path effect on the highest frequency interval of the source spectrum., and τ = 1.0, for both P and S phases, at local distances. Based on previous studies (Rama & Dushi, Near surface attenuation κ diminution factor, for Albania , 2017) , a κ = 0.055 is applied as an average effect on the wave energy at the upper part of ray paths. To account for the deeper path effect the local Q-model is applied (Dushi, 2013), in the form $Q(f) = 83f^{0.84}$. Anelastic attenuation is assumed to be frequency independent for $f < 1.0$ Hz, with a constant $Q_0 = 83$ value. It varies with frequency for $f > 1.0$ Hz, following the above relation. We have also accounted for the source effect, correcting for the geometrical spreading of body waves, in the form:

$$\mathbf{G}(\Delta,\, h) = 1/\mathbf{GD} = 1/[\Delta 2 + h2]^{1/2} \qquad (3)$$

In (3), Δ(km) is the epicentral distance and h(km) is the hypocenter depth; **GD** stands for the geo-distance term, equal to 100 km marking the transition between local and regional distances. As mention above, two ways of spectral fitting methods are applied. Due to high frequency content of the local events, small to moderate sources, visual fitting of spectra by the tangent's method is applied to approximately simulate spectra at their lower frequency interval (< f_c), and spectral decay part proportional to ω^{-2}, for higher frequencies. The other way around is applied for moderate events, in which case due to the lower frequency content of the source function, an automatic fitting is considered more effective. Both methods are demonstrated graphically in figure 2. To compute the seismic moment the following relation is applied:

$$M_0\ [\mathrm{Nm}] = [4\pi\rho v^3(s)][\mathbf{\Omega}_0/(0.6)(2.0)\mathbf{G}(\Delta,\, h)] \qquad (4)$$

In (4), Ω_0 represents the flat level of the displacement spectrum (Fig. 2). Moment magnitude of the analyzed events is computed according to the well-known relation (5), which determines M_W (Kanamori, 1977), from the seismic moment, in the form:

$$\mathbf{M_w} = 2/3\ \log_{10}(\mathbf{M_0}) - 6.06 \qquad (5)$$

Based on this procedure, the M_W is estimate for the low magnitudes using spectral analysis of S-waves. For highest magnitudes estimations from moment tensor inversion (MT) is considered for some of the processed earthquakes. To achieve a M_L-M_0 relationship we applied the linear regression method applying **Statgraphics** (ver. 18) (StatPoint_Technologies, 2009). Local magnitude values are taken as reference from the M_L reports either by ASN (TIR – international code for parametric data reports) at the Euro-Mediterranean Seismological Center (EMSC) or EMSC reports. The local preliminary M_W-M_L scaling is then determined extending for earthquakes with within 3.0 – 6.4 magnitude values. The fitted models are plotted on the graph in figure 3 and 4, and obtained statistics in table 2, respectively.

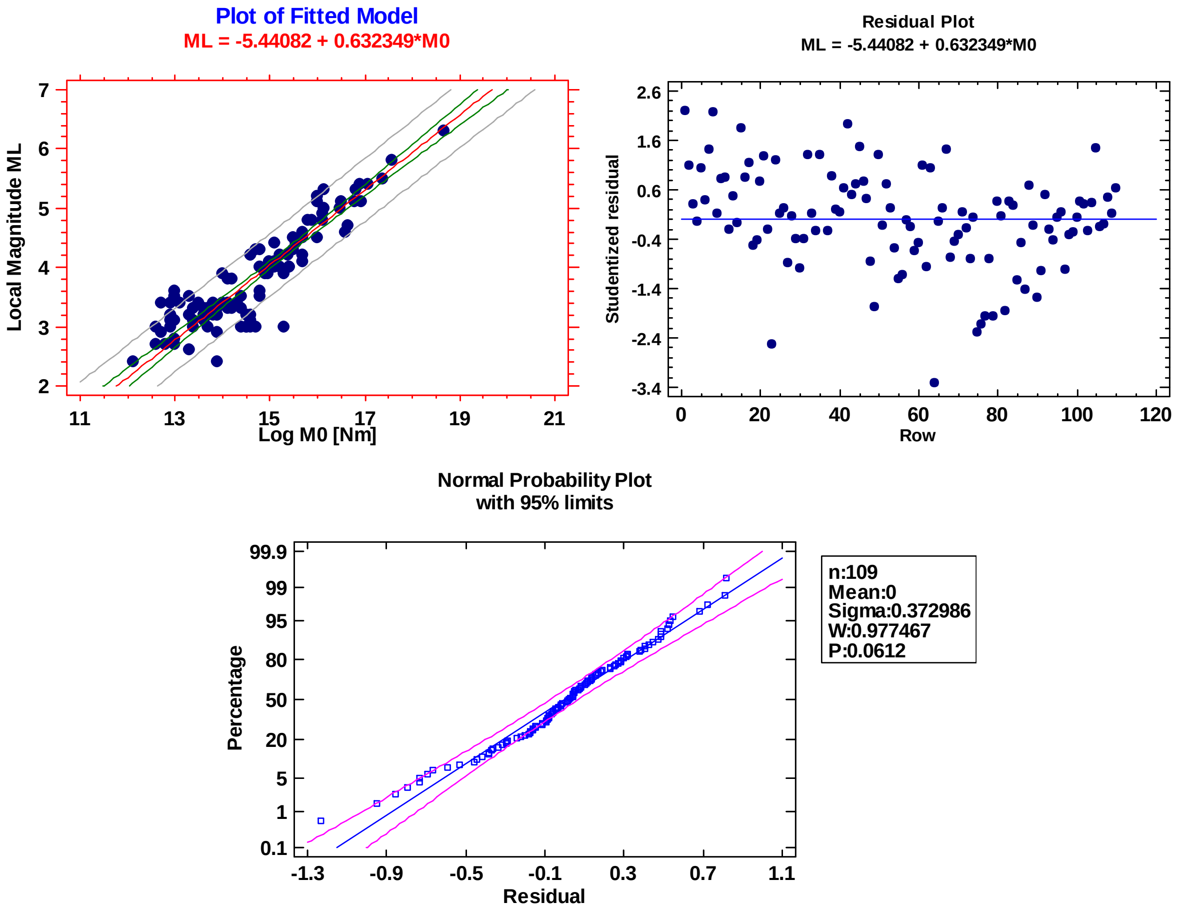


Figure 3. $M_L - M_0$ **scaling relation obtained by orthogonal regression analysis of data (M0 – the log of base 10 of the seismic moment N-m).**

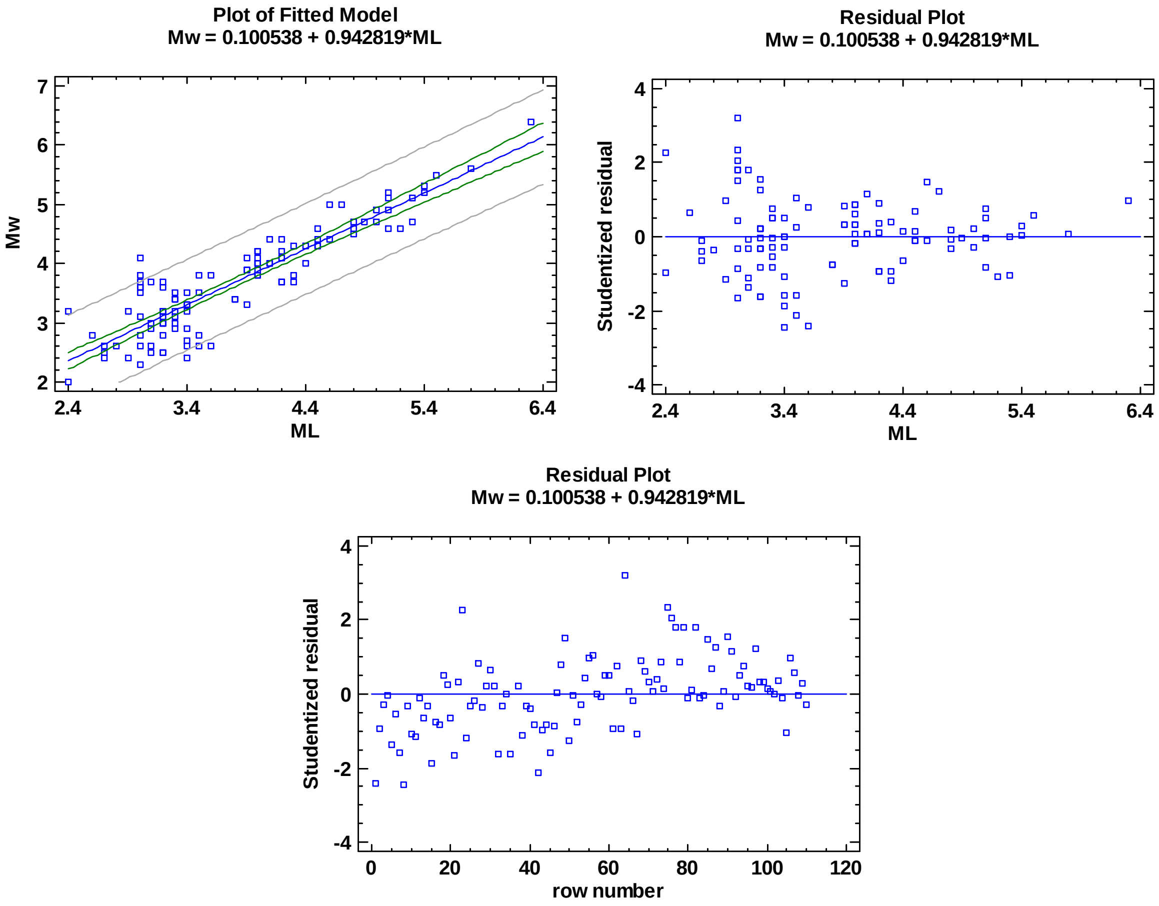


Figure 4. $M_W - M_L$ scaling relation obtained by orthogonal regression analysis of data.

IV. RESULTS AND DISCUSSION

Scaling relation analysis, fitting a linear model to describe the relationship between M_L and M_0, is completed. Results obtained for 109 observations are graphically plotted on figure 3, and given in table 2. The equation of the fitted model is (6):

$$\mathbf{M_L} = 0.632349 * \mathrm{Log}_{10}(\mathbf{M_0}) - 5.44082 \qquad (6)$$

Since the P-value in table 2 is less than 0.05, there is a statistically significant relationship between M_L and $\mathrm{Log}_{10}(M_0)$ [N-m], at the 95% confidence level. The correlation coefficient R = 0.89, indicating a moderately strong relationship between the variables.

Unlike conventional least squares, the orthogonal regression applied in this study, allows for errors in both M_L and $\mathrm{Log}_{10}(M_0)$. In estimating the model, it has been assumed that the ratio of the variance of the errors in M_L to the variance of the errors in $\mathrm{Log}_{10}(M_0)$, equals 1.0.

The fitted model minimizes the sum of squared residuals, where the residuals measure the angular distance from the observed data values to the fitted line. In this case, the estimated variance of the residuals equals 0.13912. The output also displays approximate 95% confidence intervals for the intercept and slope. Of particular importance is the confidence interval for the slope, which ranges from 0.573005 to 0.691693 (Tab. 2).

***Table 2-** Model parameters obtained for M_L-$\mathrm{Log}_{10}(M_0)$, applying orthogonal regression analysis.*

Orthogonal **Coefficients**		*Standard*	*t*	
Parameter	*Estimate*	*Error*	*Statistic*	*P-Value*
Intercept	-5.44082	0.439494	-12.3797	0.0000
Slope	0.632349	0.0299355	21.1237	**0.0000**

Correlation Coefficient = **0.898143**

Estimated error variances **95.0% Confidence Intervals**

	Variance	*Sigma*
M_L	0.0695592	0.263741
$\mathrm{Log}_{10}M_0$	0.173957	0.417081
Residual	0.139118	0.372986

	Lower limit	*Upper limit*
Intercept	-6.31206	-4.56957
Slope	0.573005	0.691693

In addition, the scaling relation is obtained for M_W-M_L, also based on the same regression analysis. The equation of the fitted model is (7):

$$\mathbf{M_w} = 0.942819*\mathbf{M_L} + 0.100538 \qquad (7)$$

Since the P-value in the table 3 is less than 0.05, there is a statistically significant relationship between M_w and M_L at the 95.0% confidence level. The R-Squared statistic indicates that the model explains 80.6441% of the variability in M_w. The correlation coefficient equals 0.89802, indicating a moderately strong relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be **0.383488**. This value is important to construct prediction limits for new observations in the future. The mean absolute error *MAE* = **0.287374** is the average value of the residuals. The Durbin-Watson (DW) statistic tests is also applied for the residuals to determine if there is any significant correlation based on the order in which they occur in the dataset. Since the P-value is less than 0.05 (table 3), there is an indication of possible serial correlation at the 95.0% confidence level.

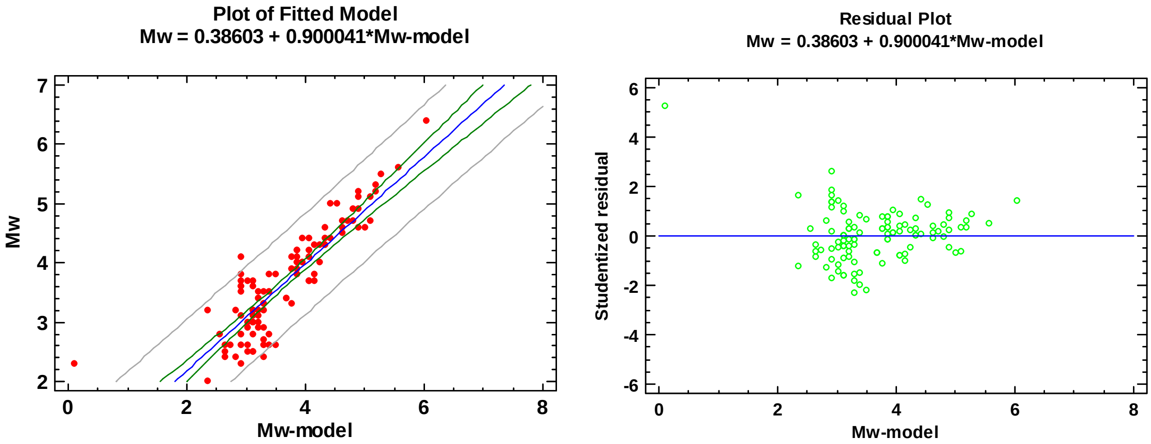
Table 3*-Mw -ML preliminary orthogonal regression model for Albania*

Coefficients *Parameter*	*Least Squares* *Estimate*	*Standard* *Error*	*T* *Statistic*	*P-Value*
Intercept	**0.100538**	0.174135	0.577356	0.5649
Slope	**0.942819**	0.0446537	21.114	0.0000

Analysis of Variance

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Model	65.561	1	65.561	**445.80**	**0.0000**
Residual	15.7357	107	0.147063		
Total (Corr.)	81.2967	108			

Correlation Coefficient = **0.89802**
R-squared = **80.6441 %**
R-squared (adjusted for d.f.) = 80.4632 %
Standard Error of Est. = **0.383488**
Mean absolute error = **0.287374**
Durbin-Watson statistic = 1.36399 (**P=0.0004**)
Lag 1 residual autocorrelation = **0.292151**



Plot of Fitted Model
Mw = 0.38603 + 0.900041*Mw-model

Residual Plot
Mw = 0.38603 + 0.900041*Mw-model

Figure 5. M_W – M_W-model regression analysis, fitted model and the residuals obtained.

Simple regression Analysis is applied to compare the M_W as computed from (5) based on the seismic moment values from spectral analysis and the regional databases (Fig. 5). The dependent variable M_W is compared with the independent variable M_W-model. The regression line is well fitted to the computed data, with a correlation coefficient R = 0.873345 (R-squared = 76.2731 %). The estimated standard error is Std.Err = 0.427594 and a mean absolute error = 0.318484. Other statistical data comprise the Durbin-Watson statistic = 1.40731 (P=0.0008) and the Lag 1 residual autocorrelation = 0.274369. Results are given in the table 4, while the graphical results are plotted on figure 5. The equation of the fitted model is (8):

$$\boldsymbol{M_W} = 0.38603 + 0.900041*\boldsymbol{M_W\text{-}model} \qquad (8)$$

***Table 4** - linear regression results of Mw-Mw-model*

Coefficients

Parameter	*Least Squares Estimate*	*Standard Error*	*T Statistic*	*P-Value*
Intercept	0.38603	0.181519	2.12666	0.0357
Slope	0.900041	0.0483042	18.6328	0.0000

Analysis of Variance

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*
Model	63.4773	1	63.4773	347.18
Residual	19.7464	108	0.182837	
Total (Corr.)	83.2236	109		

Since the P-value is less than 0.05, there is a statistically significant relationship between Mw and Mw-model at the 95.0% confidence level. The correlation coefficient 0.873345, indicates a moderately strong relationship between the variables.

V. CONCLUSION

Scaling relation models, for local and routine determination of seismic source data and M_W of moderate to strong earthquakes in Albania and surroundings, are determined based on spectral analysis results, regional moment tensor inversion data and the application of the orthogonal regression analysis, on selected dataset. Correspondingly two scaling relations are derived and their statistical significance is analyzed in details. Models are significant at the 95.0% confidence level. Of particular importance is the confidence interval for the slope, of the $M_L - M_0$ scaling model, which ranges approximately within the interval 0.57-0.69. While, the achievements on the M_W-M_L scaling model indicates a moderately strong relationship between both variables based on the correlation coefficient. Finally, two local parametric relations have the form:

$$\mathbf{M_L} = 0.632349 * \mathrm{Log}_{10}(\mathbf{M_0}) - 5.44082 \qquad R = 0.89,\ Sd = 0.13912$$

$$\mathbf{M_w} = 0.942819 * \mathbf{M_L} + 0.100538 \qquad R = 0.9,\ Sd = 0.38349$$

Both models are of practical interest, involve local dependency and are important for the earthquake source parameters analysis on routine bases for the earthquakes within the magnitude range $3.0 \leq M_W \leq 6.4$, in Albania. Although preliminary and based on a small group of representative earthquakes, both scaling relations show good accordance although with previous regional models, serving also as a good basis for future improvements.

ACKNOWLEDGEMENTS

Many thanks devoted to the Department of Seismology (IGEWE) monitoring staff for their contribution on data processing and archiving with daily basis, and to the technical staff contributing in the permanent operation of the Albanian Broadband Seismic Network.

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Besian Rama, et. al. "Preliminary Scaling Relations of Moment Magnitude With Local Magnitude And Seismic Moment, For Albania."*American Journal of Engineering Research (AJER)*, vol. 10(6), 2021, pp. 85-98.