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Duration Magnitude Scale for Anbar Seismic Station (ANB1), Iraq

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ABSTRACT

Measuring an earthquake's magnitude is a routine task at all seismological observatories. The current study aims to derive the earthquake duration magnitude scale for Anbar seismic station (ANB1), which is one of the stations of the Mesopotamian Seismological Network (MPSN) in Iraq. Ninety-five earthquakes were selected based on the clarity of the seismic signal coda to derive duration magnitude from linear regression between local magnitude M_L extracted from International Seismological Center (ISC) bulletins and signal coda length (t_c). The obtained relation is:

$$M_D = 1.085 + 1.263\, Log_{\,tc} + 0.03$$

The results of the regression analysis showed a high correlation coefficient (0.86) with a significance level less than 0.05 and this reflects the strength of the relationship and the reliability of its use in calculating the earthquake magnitude. The derived relationship was used to estimate M_D for 41 events recorded by the ANB1 station. To build a scaling relationship between M_D and M_L, M_D values were compared with M_L values for the same events where regression analysis results showed significant strong correlation relationship at $p < 0.05$:

$$M_D = 0.9 + 0.78\, M_L$$

This relationship is used quickly and reliably in M_D calculation by M_L for earthquakes recorded by ANB1 and vice versa.

Introduction

Earthquake Magnitude, which is a measure of the total energy release during the process of rupture, is one of the most versatile and frequently used source parameters in quantifying the size of an earthquake [1]. Nowadays, estimating an earthquake's magnitude is a common procedure in the analysis of seismological data. Different scales are used to calculate the earthquake magnitude depending on the amplitude, duration, amplitude and period, type of seismic waves (M_L, M_D, mb, M_S and M_W), for more details, see [2]. The recording distance, the wave's path of propagation through various mediums and the geology near the recording site all affect the amplitude and duration of seismic signals [3].

Most of the magnitude determinations make use of the maximum peak-to-peak amplitude as read on the seismograms. But, it has been observed time and again that amplitude measurements are often obliterated due to a variety of reasons like saturation of the amplification of the recording instrument as a result of practical limitations on dynamic range and faint trace on recording devices.

The coda length or duration magnitude (M_C or M_D) employed and continued to be employed in the calculation of the amount by a large number of seismic networks and stations. The magnitude of wave coda length (duration) is defined as the total duration in seconds of the earthquake recording from the start time of the P-wave to the end of the specific signal as the point where the S-wave coda signal is no longer observed above the noise level [2]. The first study was made by, [4] who discovered a linear relationship between the logarithm of the surface-wave train's duration, the epicentral distance, and the magnitude of teleseisms (which vary from 5 to 8). This method has been applied since the 1960s and so far in many studies around the world to calculate the magnitude of local, regional and teleseismic earthquakes recorded by seismic networks and stations, e.g., in Sakhalin, Russia [5], Japan, [6], Puget Sound, USA [7], USA [8],

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Southern California, USA [9], USA [10], Oroville, California, USA [11], Southern California, USA [12], India [1] Northern Arizona, USA [13], northern Baja California, Mexico [3], Northwestern Italy [14], Italy, [15] Kuwait [16] Southern Italy [17], Northeast India [18] Central Iran [19], [20] Southern California, USA [21] and Canada [22].

In Iraq, Alsinawi & Al-Heety [23] investigated the relationship between the local magnitude and coda duration for small earthquakes recorded in Iraq. An empirical duration magnitude equation was derived from the earthquakes data of the Iraqi Metrological Organization and Seismology (IMOS) [24].

The main purpose of this paper is to develop an empirical magnitude duration formula by using the seismic signal duration ($\tau coda$) for data obtained from Anbar seismic station (ANB1) which is one of the stations of the Mesopotamian Seismological Network (MPSN) in Iraq. The derived equation will be used to calculate the magnitude of the earthquakes recorded by ANB1 seismic station.

Materials and Methods

Anbar Broadband Seismic Station (ANB1)

ANB1 seismic station is located within the Anbar governorate, specifically in the University of Anbar Campus at latitude 33.4018°N and longitude 43.2576° E (Figure 1).

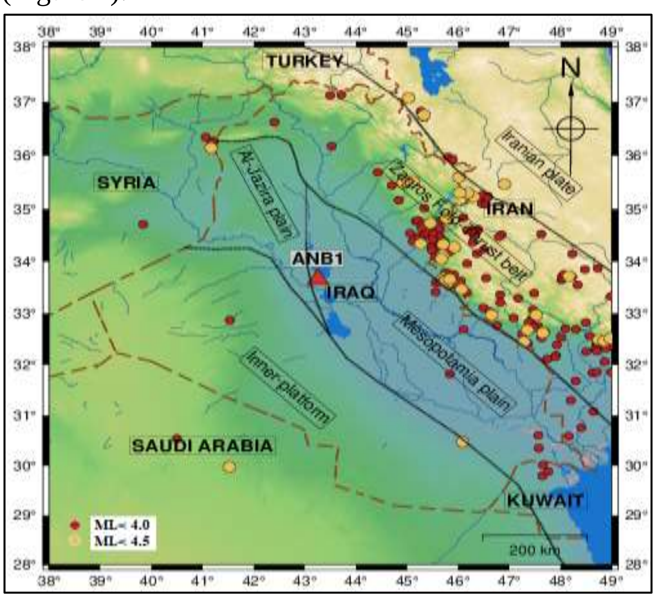

Figure1. Location of the ANB1 seismic station represented by a red triangle and distribution of the earthquakes recorded by the ANB1 seismic broadband station used in this study for the period from 2018 to 2023.

This station was launched in November 2018, which operates with the local Mesopotamian Seismological Network (MPSN) in Iraq. The ANB1 seismic station is providing with CMG40T/DM24 broadband seismometers. The advantage of seismometers in tis station is that it operates with three component digitizers and it is equipped with a high-gain (about 10").

Earthquake Database

Seismic waveform data of 207 earthquakes from Anbar broadband seismic station (ANB1) of Mesopotamian network (MP) from period December 2018 to September 2023 were collected and analyzed using CPS computer software (Figure1). The range of magnitude, hypocentral distance and the focal depth of the sampled earthquakes are $4.0 \leq M_L \leq 6.0$, 202 to 564 km and 0-98 km, respectively. The source parameters of these earthquakes were extracted from the International Seismological Centre (ISC). A 15-minute window from the seismogram was interrupted to ensure that the seismic event with coda was fully visible for the duration measurement.

To ensure accurate determination of coda length the window extracted from the seismic record was filtered using Butterworth filter (Figure 2). Although there are many different kinds of filters, Butterworth filters are nearly always utilized in practical analysis due to their advantageous qualities: There are no ripples or ringing in the pass band and the corner frequency responds quite smoothly while staying constant regardless of the filter's sequence. In addition to decreasing the amplitude outside of the pass band, filters also have the effect of altering the phase, which can have significant effects on the arrival times of seismic phases [2].

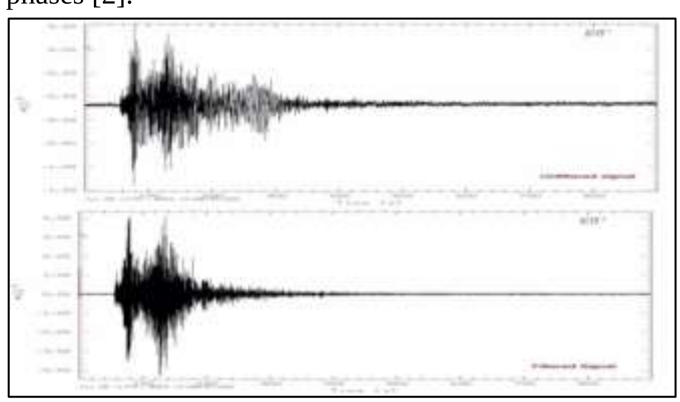

Figure2. The effect of using Butterworth filter on the seismic signal. The event origin time is 2023-06-28 (0179), 19:08:37.020, epicentral distance is 390.2969 km, the depth is 10 km and M_L = 4.7.

After filtering, we have selected 136 earthquakes based on the clarity of the seismic signal coda. However, it is necessary to mention that all records with very high noise level and extremely weak signals seismic for which seismic signal coda is difficult to identify have been removed. The duration measurements were done on filtered records.

Duration Magnitude Scale

The duration magnitude is defined by [9] and [10] as:

$$M_D = a + b\, log_{tcoda} + c\,\Delta + Sc \qquad (1)$$

Where M_D is duration magnitude, $\tau coda$ is the duration of signal in seconds, Δ is hypocentral distance in kilometers, a, b and c are constants, and Sc is the station correction. The seismic signal duration is evaluated on the vertical component of seismogram records as the time from the first P-arrival time to the time along the trace at which the wave amplitude has decreased to the noise level [17], (Figure 3).

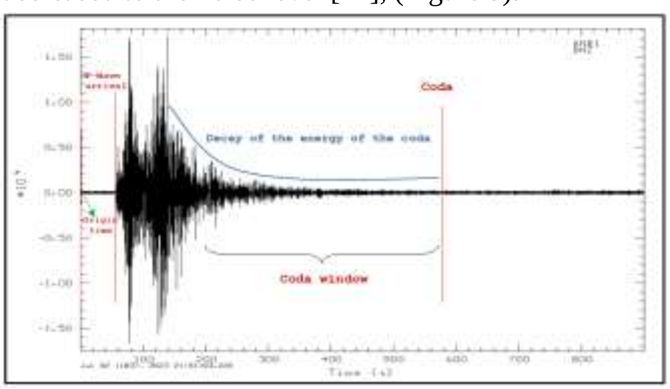

Figure3. The seismogram record displaying the vertical component for one of the data recorded by the ANB1 seismic station and the time period between the first P-arrival time to the point on the trace where the wave amplitude decreases to the noise level. The event origin time is 2023-07-02 (0183), 21:51:03.220, epicentral distance is 397.9601 km, the depth is 10 km and M_L= 4.4.

The backscattering of seismic waves is most likely the primary determinant of the coda length, or duration of the seismic signal [25]. Generally, with distance increases such waves dwindle slowly. Sensitivity of the instrument is also not a crucial factor for duration of signal because stations are adjusted according to the background noise level [8].

The hypocenteral distance was calculated by applying the Pythagorean Theorem. This theory states that the square of the length of the hypotenuse is equal to the sum of squares of the lengths of other two sides of the right-angled triangle. The equation is given by:

$$Hyp.d^{\,2} = Epi.d^2 + D^{\,2} \qquad (2)$$

Where Hyp.d is hypocentral distance refers to the distance between the earthquake hypocenter and the station, Epi.d is epicentral distance which refers to the ground distance from the epicenter to the station and D is Focal Depth in km (Figure 4).

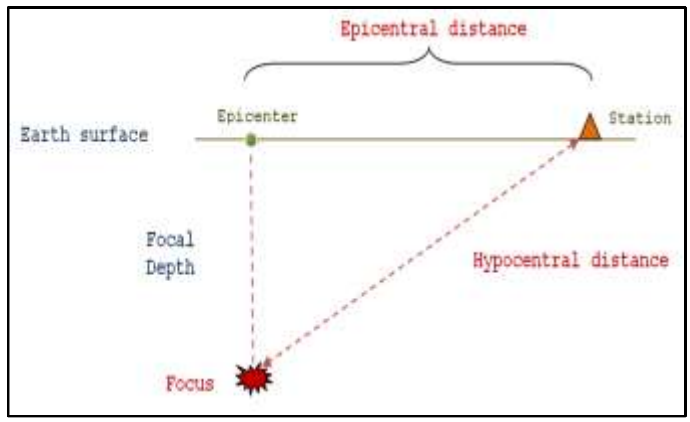

Figure4. The mechanism of converting the epicentral distance to the hypocentral distance by applying the Pythagorean Theorem.

Station Correction (Sc)

To increase the accuracy of magnitude estimates, station correction need to be incorporated into a duration-magnitude scale [3]. To reduce the consistent overestimation or underestimating of magnitude values acquired at each station, station correction coefficients are introduced [17]. The station correction (Sc) of ANB1 station was calculated using the following formula [15]:

$$Sc = \frac{\sum(M_L - M_D)}{N} \qquad (3)$$

Where Sc is station correction at ANB1 seismic broadband station of the network, M_L is the local magnitude for the earthquake events provided by the ISC bulletin, M_D is the duration magnitude estimated for earthquake events at the ANB1 station and N is the number of events recorded at station.

The general characteristics of the region where the station is located are reflected in a positive or negative coefficient. When the recorded signals may be influenced more by local site properties, the further Sc deviates from zero [17].

Results and Discussion

As was previously mentioned, equation (1) is the overall functional relationship used for the duration magnitude computation. Because of its weak distance dependence, it is frequently challenging to determine the constant c with accuracy [2]. Several authors chose to set the constant c to zero e.g. [26, 11, 15, and 17]. In the current study, we assumed the constant c equals zero. To calibrate the duration magnitude scale, we used the local magnitude (M_L) as a reference, that is, we assumed M_D = M_L for each selected earthquake. Ninety-five earthquakes were selected to calibrate the M_L with the coda length. The regression analysis was employed to obtain the relationship between M_L and $\tau coda$ (Figure 5). We determined the following relationship by using a least-square linear regression approach on the coda length:

$$M_D = 1.085 + 1.263 \, Log_{tc} \qquad (4)$$

With a correlation coefficient R = 0.86. Because the correlation coefficient is significantly different from zero, there is enough information to draw the conclusion that t_c and M_D have a significant linear relationship. The obtained significant linear relationship between M_D and $\tau coda$ can be used reliably to calculate the earthquakes magnitude recorded at ANB1.

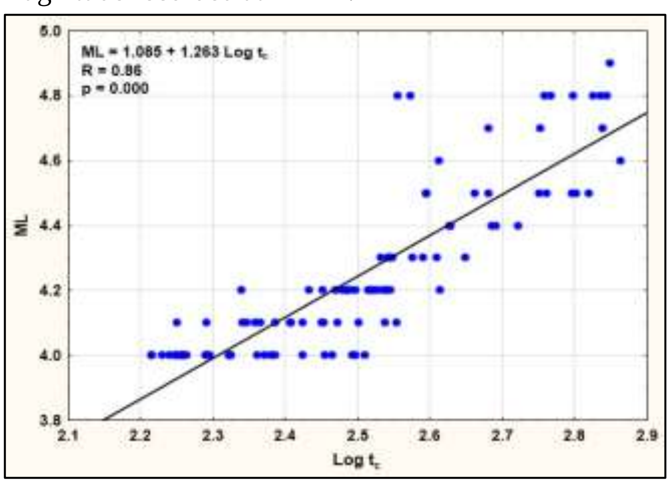

Figure5. Local magnitude M_L as a function of logarithm of duration for the selected events.

The station correction coefficient (S_C) was calculated for ANB1 station by using equation (3), which was valued 0.03. The positive value of (Sc) indicated the station was installed in sites containing young, unconsolidated sediments, which are distinguished by low acoustic impedance (low density and low velocity). This tends to overestimate earthquake duration magnitude M_D because seismic signal undergoes reverberation, amplification, and attenuation with the strong dissipation in such media [17]. By addition the Sc for ANB1 station, equation (4) is then generalized as:

$$M_D = 1.085 + 1.263 \, Log_{tc} + 0.03 \qquad (5)$$

The equation (5) was used to estimate the M_D for 46 events recorded by ANB1 station. Results of application of equation (5) were listed in Table 1. To derive a scaling relationship between M_D and M_L, M_D and M_L values were compared to 41 events recorded in ANB1 (Figure 6).

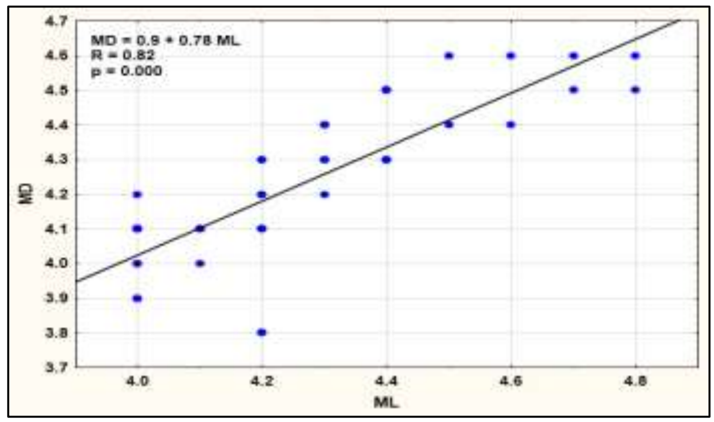

Figure 6. Scaling relationship between local magnitude (M_L) and duration magnitude.

The following relationship was obtained by a linear regression analysis of M_L data and associated M_D estimates:

$$M_D = 0.9 + 0.78 M_L \qquad (6)$$

This relationship is used quickly and reliably in M_D calculation by M_L for earthquakes recorded by ANB1 and vice versa.

Conclusions

The following obtained relationship between M_D and coda length tc is reliable to calculate the earthquakes recorded by ANB1 station:

$$M_D = 1.085 + 1.263 \, Log_{tc} + 0.03$$

The following derived scaling relationship between M_D and M_L is used quickly and reliably in M_D calculation by M_L for earthquakes recorded by ANB1 and vice versa:

$$M_D = 0.9 + 0.78M_L$$

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Table 1: Duration Magnitude (MD) estimation using equation (5) for 41 events recorded by ANB1 Station.

Event date	Event time	Long. (°E)	Lat.(°N)	Depth (km)	M_L	tp (sec.)	t (sec.)	tc (sec.)	Log tc	Epi. Dist. (km)	Hyp. Dist. (km)	Log hyp	M_D without Sc	M_D with Sc
2021-05-07	19:48:44.58	35.1914	46.5422	10	4.4	54.310	643.500	589.190	2.770	361.3929	361.531	2.558	4.5	4.6
2021-05-21	23:50:41.13	35.0812	46.5332	10	4.4	53.430	615.230	561.800	2.749	354.2994	354.440	2.549	4.5	4.5
2021-05-23	19:57:41.84	35.2109	46.5678	10	4.0	55.290	282.730	227.440	2.356	364.5178	364.654	2.561	4.0	4.0
2021-07-09	15:41:20.51	36.7557	45.3308	18.5	4.8	59.368	591.800	532.432	2.726	417.0256	417.435	2.620	4.5	4.5
2021-07-09	17:31:12.54	36.8259	45.2713	17.4	4.0	61.840	341.080	279.240	2.445	421.5594	421.918	2.625	4.1	4.2
2021-07-18	22:09:22.59	34.7061	39.8354	17.4	4.0	51.390	394.700	343.310	2.535	347.1813	347.617	2.541	4.2	4.3
2021-07-31	23:41:22.62	34.4747	45.2283	10	4.0	37.000	312.550	275.550	2.440	217.4376	217.667	2.337	4.1	4.1
2021-09-08	15:43:02.34	34.7130	45.2933	12.5	4.4	38.330	438.650	400.320	2.602	237.4492	237.777	2.376	4.3	4.4
2021-09-24	23:43:10.06	36.6225	42.4039	1	4.1	55.565	314.910	259.345	2.413	365.4322	365.433	2.562	4.1	4.1
2021-09-28	08:58:24.41	34.5788	45.4344	9.7	4.2	38.640	328.090	289.450	2.461	239.5811	239.777	2.379	4.1	4.2
2021-09-28	11:46:12.83	34.5238	45.4028	15.2	4.2	39.175	376.860	337.685	2.528	233.8958	234.389	2.369	4.2	4.3
2021-12-26	20:39:32.80	34.4960	45.3360	16.1	4.2	35.840	327.420	291.580	2.464	227.0616	227.631	2.357	4.1	4.2
2022-01-05	01:09:37.61	34.4811	45.6028	10.2	4.3	40.350	403.650	363.300	2.560	247.4514	247.661	2.393	4.3	4.3
2022-01-06	18:40:51.30	30.6060	47.5640	16.7	4.0	89.870	373.520	283.650	2.452	510.8973	511.170	2.708	4.1	4.2
2022-01-10	18:29:47.86	35.5272	44.9269	10	4.5	44.884	674.160	629.276	2.798	281.0473	281.225	2.449	4.6	4.6
2022-01-10	20:11:16.95	35.4789	44.9228	10	4.6	44.766	500.750	455.984	2.658	276.3905	276.571	2.441	4.4	4.4
2022-02-20	12:45:27.65	32.6877	46.1011	10	4.3	45.100	338.40	293.300	2.467	276.8576	277.038	2.442	4.2	4.2
2022-02-20	12:46:04.31	30.3505	47.5717	15	4.0	07.810	184.390	176.580	2.246	529.5024	529.714	2.724	3.9	3.9
2022-03-13	05:04:27.07	34.5734	45.3696	10	4.2	40.520	209.390	168.870	2.227	234.2604	234.473	2.370	3.8	3.9
2022-03-19	18:47:02.89	34.4673	46.7939	10	4.4	56.934	414.034	357.100	2.552	347.3256	347.469	2.540	4.3	4.3
2022-04-08	06:20:57.20	33.4000	46.1660	11.5	4.1	43.510	290.790	247.280	2.393	270.2951	270.539	2.432	4.1	4.1
2022-04-16	19:00:22.58	34.5286	45.5069	0	4.0	46.140	300.350	254.210	2.405	242.3582	242.358	2.384	4.1	4.1
2022-06-04	01:49:09.07	32.8220	48.4920	10	4.4	68.030	485.240	417.210	2.620	492.2245	492.326	2.692	4.3	4.4
2022-06-05	02:26:30.10	33.9590	46.1730	6	4.2	44.000	406.970	362.970	2.559	277.0567	277.121	2.442	4.3	4.3
2022-09-28	16:18:03.02	33.3614	46.8173	10	4.3	58.470	434.030	375.560	2.574	330.9213	331.072	2.519	4.3	4.3
2022-12-16	00:09:54.81	37.1309	43.7122	0	4.1	62.570	336.800	274.230	2.438	415.4832	415.483	2.618	4.1	4.1
2023-01-28	13:53:10.18	33.6590	45.8340	10	4.6	37.700	645.610	607.910	2.783	240.7865	240.994	2.382	4.6	4.6
2023-02-04	02:45:45.95	34.3241	45.7059	10	4.7	39.085	613.650	574.565	2.759	248.3554	248.556	2.395	4.5	4.6
2023-02-24	23:25:26.16	36.1751	43.5213	0	4.3	49.588	495.300	445.712	2.649	308.3856	308.385	2.489	4.4	4.4
2023-03-12	06:35:32.50	34.2696	45.6421	10	4.0	42.960	225.340	182.380	2.260	240.5782	240.785	2.381	3.9	3.9
2023-03-25	19:13:32.37	32.6182	47.6519	10	4.8	60.265	764.570	704.000	2.847	419.2517	419.370	2.622	4.6	4.7
2023-04-26	05:18:17.28	34.6422	45.2800	98	4.0	33.360	253.010	219.650	2.341	231.8025	251.667	2.400	4.0	4.0
2023-04-26	21:06:56.15	34.3892	45.2965	10	4.2	39.164	331.870	292.706	2.466	217.9056	218.134	2.338	4.2	4.2
2023-05-07	19:34:50.34	34.1445	48.2296	0	4.2	59.790	344.470	284.680	2.454	467.3832	467.383	2.669	4.1	4.2
2023-05-13	14:18:00.22	34.4274	45.5016	0	4.1	43.594	286.590	242.996	2.385	236.451	236.451	2.373	4.0	4.1
2023-06-04	04:51:10.12	34.2299	46.5001	0	4.2	57.820	212.240	154.420	2.188	313.6442	313.644	2.496	3.8	3.8
2023-06-26	06:41:30.22	37.1215	43.4920	10	4.3	59.885	496.600	436.715	2.640	412.9318	413.052	2.616	4.4	4.4
2023-06-28	19:08:37.02	32.4450	47.2780	10	4.7	55.645	724.295	668.650	2.825	390.2969	390.424	2.591	4.6	4.6
2023-07-02	21:51:03.22	32.4203	47.3544	10	4.4	56.400	578.070	521.670	2.717	397.9601	398.085	2.599	4.5	4.5
2023-09-10	21:43:49.98	35.1620	44.8350	10	4.5	37.728	537.490	499.762	2.698	243.1646	243.370	2.386	4.4	4.5
2023-09-13	20:11:38.43	32.3614	48.4052	0	4.2	71.760	428.870	357.110	2.552	494.7648	494.764	2.694	4.3	4.3

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مقياس مقدار المدة لمحطة الأنبارالزلزالية (ANB1)، العراق

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الخلاصة:

يمثل تقدير مقدار الزلزال مهمة منتظمة في جميع المراصد الزلزالية. تهدف الدراسة الحالية إلى اشتقاق مقياس مدة الزلزال لمحطة الأنبار الزلزالية (ANB1)، وهي إحدى محطات شبكة وادي الرافدين لرصد الزلازل (MPSN) في العراق. تم اختيار خمسة وتسعون زلزالا بناءً على وضوح كودا الإشارة الزلزالية لاستخلاص حجم المدة من الانحدار الخطي بين القدر المحلي M_L المستخرج من نشرات المركز الزلزلي العالمي (ISC) وطول كودا الإشارة (tc). العلاقة التي تم الحصول عليها هي:

$$M_D = 1.085 + 1.263\, Log_{\,tc} + 0.03$$

أظهرت نتائج تحليل الأنحدار معامل ارتباط مرتفع (0.86) مع مستوى أهمية أقل من 0.05 وهذا يعكس قوة العلاقة وموثوقية أستخدامها في حساب مقدار الزلزال. استخدمت العلاقة المشتقة لتقدير M_D لـــ 41 حدثًا سجلتها محطة ANB1. لبناء علاقة قياس بين M_D و M_L ، قورنت قيم M_D مع قيم M_L لنفس الهزات حيث أظهرت نتائج تحليل الانحدار علاقة ارتباط قوية مهمة عند مستوى الأهمية ($p < 0.05$) :

$$M_D = 0.9 + 0.78\, M_L$$

تستخدم هذه العلاقة بسرعة وبموثوقية في حساب M_D بدلالة M_L للهزات الأرضية التي تسجلها محطة الأنبار الزلزالية ANB1 وبالعكس.

الكلمات المفتاحية: *مقدار المدة ؛ طول كودا ؛ المقدار المحلي ؛ شبكة وادي الرافدين.*