Research Article
Academic Platform Journal of Natural Hazards and Disaster Management
4(1), 12-21, 2023 DOI: 10.52114/apjhad.1211643

Determining the Success of Strong Motion Records in Calculating P-Wave Moment Magnitude

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Received: / Accepted: 30-November-2022 / 05-May-2023

Abstract

Earthquake early warning systems have high importance and continuously improving using different analysing techniques. The system depends on calculating a magnitude quickly with as high accuracy as possible. Large earthquakes that have tsunami potential occurred and will be occurred, especially in the Mediterranean and Aegean Seas. Turkey has settlements along these coastlines. In practice, weak-motion (velocity) records are generally used to determine the magnitude, but these seismic records have a disadvantage: a clipping problem around the epicentre. Up to now, there has been little work on studying the strong-motion (acceleration) records to calculate the magnitude of an earthquake quickly and with high accuracy. This study focused on estimating the P-wave moment magnitude using P-wave body waves recorded at strong motion seismic stations caused by possible tsunami source region earthquakes. Therefore, we used three earthquakes with a magnitude larger than 6.0 Mw. The difference between the Global Centroid Moment Tensor (GCMT) moment magnitude is about ±0.2 m.u. which is acceptable considering an early warning purpose.

Keywords: Early warning, Strong motion, The Mediterranean, Turkey, Earthquake

1. Introduction

The tectonic structure around Turkey can be defined as caused by the movements of the main plates, such as African, Arabian, and Eurasian. These movements resulted in an outcrop of main fault zones in Turkey named North Anatolian Fault Zone (NAFZ), Eastern Anatolian Fault Zone (EAFZ) inland and in the Mediterranean Sea as trench structures that African plate is subducting beneath Anatolia through the Hellenic and Cyprus arcs. Figure 1 shows the main tectonic interaction in the study region. Some tsunami-sourced strong earthquakes occurred in 92 BC, 551 AD, 1034, 1068, 1202, 1222, 1303, 1546 and 1759 [1]. Western Hellenic arc, south of Crete, with Eastern Hellenic arc regions, are defined as tsunamigenic sources [2]. Ozel et al. [3] estimated the maximum tsunami wave travel time to Turkish coastlines, and they found that the time is about 10 min for Marmaris and Dalaman, whereas 15-20 min for Fethiye and Kas towns.

Tsunami early warning system establishment initiatives started after the 2004 Sumatra earthquake, and many people lost their lives within a couple of hours. The P-wave moment magnitude calculation method uses very broad-band P-wave displacement seismograms

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derived from the first P-wave part of a seismogram proposed and applied by Tsuboi et al. [4], Tsuboi and Whitmore [5] and Tsuboi [6]. Their studies indicated that the Mw (GCMT) and Mwp agreed well. Whitmore et al. [7] proposed a linear relation between Mwp and Mw (GCMT), and it can be practically added by 0.2 to Mwp. These calculations are based on far-field recordings of tsunamigenic earthquakes. In contrast, Hishorn et al. [8], Tezel and Yanik [9], and Tezel [10] showed that the Mwp could be calculated using local and regional earthquakes. Although these studies used weak-motion velocity seismograms from broadband seismometers, Tezel [11] used strong motion records for the calculations. This study focused on applying and testing the Mwp calculation technique to the strong-motion (acceleration) seismic records considering only tsunamigenic sourced earthquakes.

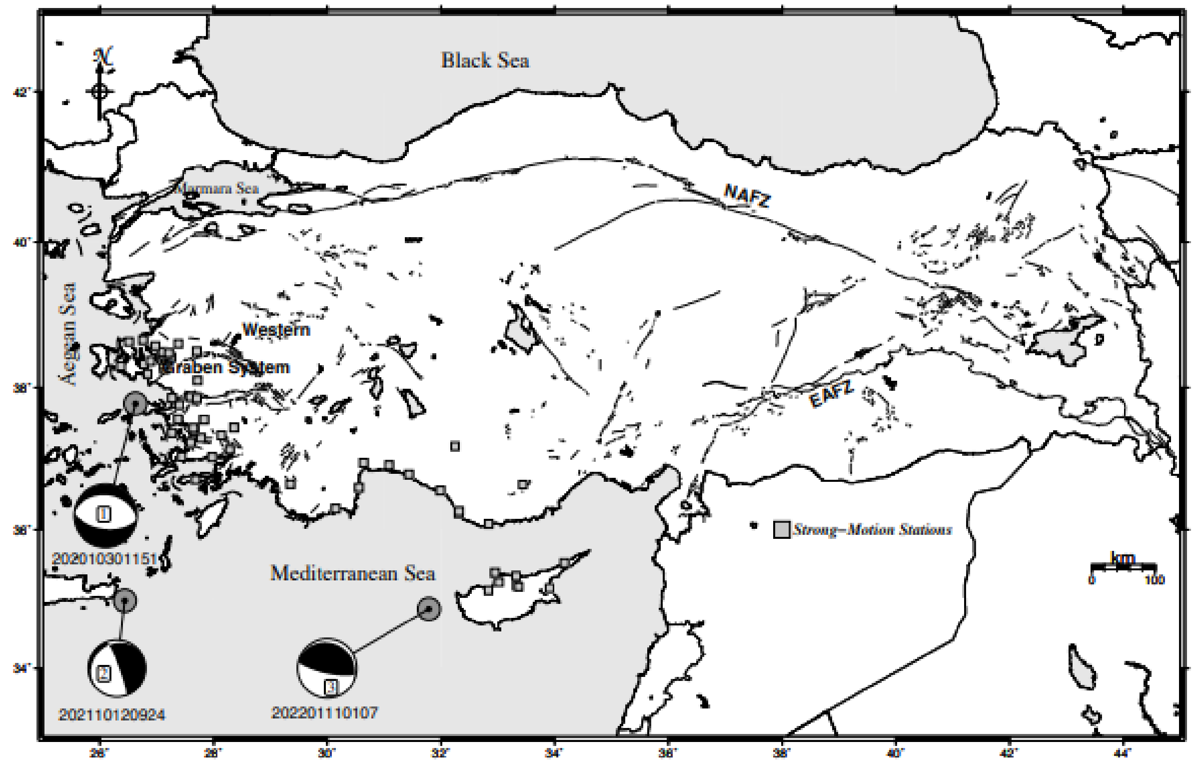

Figure 1. Simplified tectonic map of Turkey and surrounding with used events epicentres

2. Data and Method

Tsuboi et al. [4] described the broadband P-wave moment magnitude, Mwp, derivation from the vertical component of far-field P-wave displacement. P-wave displacement was produced from both velocity seismograms and acceleration seismograms in this study and used to obtain a mean Mwp magnitude.

This technique depends on the assumption that seismic moment can be obtained from the P-wave portion of broadband vertical displacement waveforms u_z,

$$M_0 = \frac{4\pi\rho\alpha^3 r}{F^p}\left|max \int u_z(x_r, t)dt\right| \quad (1)$$

where 〉 and 〈 are the average density and P-wave velocity along the propagation path, respectively, r is the epicentral distance, and F^p is the radiation pattern.

The seismic moment is calculated from the maximum amplitude in the selected P-wave portion. The moment magnitude is computed at each station with no correction for the radiation pattern using the standard moment magnitude formula,

$$M_w = \frac{(logM_0 - 9.1)}{1.5} \tag{2}$$

where M_0 is in Nm [12, 13].

As stated above, the P-wave moment magnitude determination technique was proposed by Tsuboi et al. [4]. We selected three earthquakes in the last two years with a magnitude larger than 6.0 at tsunamigenic sources (Figure 1). Briefly, P-wave moment magnitude, Mwp, derived from the vertical component P-wave displacement derived from the strong-motion seismic records for this study and calculated Mwp for each seismic station. Mwp has been calculated by adding 0.2 to obtain Mw because of the Whitmore [7] correction. We did not apply this correction in this study. Despite some studies using fixed time windows and P-wave velocity in calculations, some studies use variable P-wave velocity values dependent on travel time with distance.

The most significant advantage of using strong motion records instead of velocity seismograms is overcoming the clipping problems in the seismic records recorded at stations with too short epicentral distances [11]. In contrast, others use relations dependent on epicentral distance. The Mwp is affected by the direct selection of a time window that can cause underestimates or overestimates in calculations. In this study, we used a fixed P-wave velocity (Vp=7.0 km/s) and a time window of 3 sec on the strong motion seismic records.

Strong motion seismic stations equipped with Guralp CMG-5T and GeoSIG-type seismometers have 100 Hz flat frequency response that gives a chance to use in Mwp calculations as Broadband seismometers. Hypocentral parameters of the used events are listed in Table 1, with the number of stations used in each analysis. All used seismograms were downloaded from the Disaster and Emergency Management Presidency and Ministry of Interiors (AFAD) databases.

Table 1. Results of this study with focal parameters of used events

No	Date	O.Time	Latitude	Longitude	Depth	Mw (GCMT)	This Study (Mwp)
1	30/10/2020	11:51:35	37.78	26.63	12	7	7
2	12/10/2021	09:24:09	34.98	26.44	24	6.4	6.6
3	11/01/2022	01:07:57	34.86	31.79	26.4	6.6	6.6

A thirteen-second window of the acceleration signal that starts 10 sec before P-wave arrival and three seconds after is integrated to obtain the P-wave displacement seismogram and seismic moment. The arithmetic gathers the Mwp value of each event mean of all Mwp values calculated at each seismic station using the SAC2000 [14] seismic analysing program.
Data process steps are summarised below:

- ◊ Apply four poles Butterworth filter with corner frequencies of 0.1 and 25 Hz for all vertical components,
- ◊ Pick P-wave phases,

◊ Cut the records 10s before P-wave onset and 3s after,
◊ Remove trend and mean from the records,
◊ Calculating Mwp from acceleration records by converting them into displacement records (Figure 2).

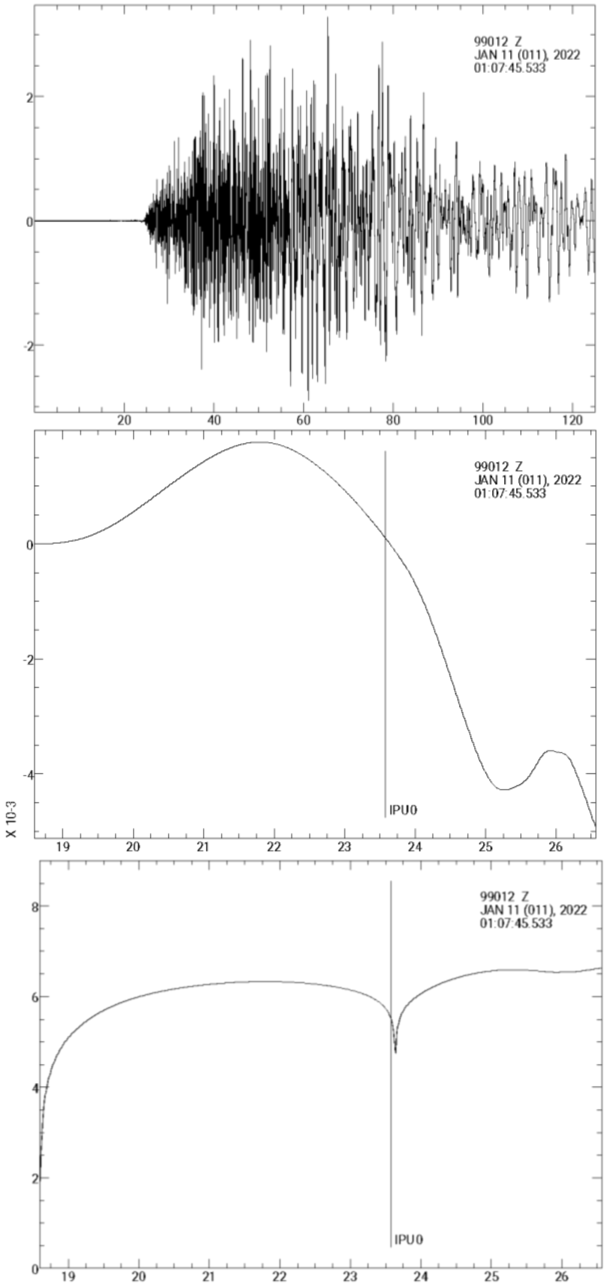

Figure 2. Mwp calculation procedure for the 99012 station. The acceleration waveform (top), integrated displacement (middle) and the Mwp graph (bottom). IPU0 stands for impulsive, up, P-wave.

3. Results

We used three tsunamigenic-sourced earthquakes to determine and compare the Mwp with Mw (GCMT). Some information will be given for each event with its results below sub-sections.

3.1. Event 1 (2020/10/30, Samos Island)

The Samos Island earthquake caused small tsunami waves that arrived on Samos Island and Seferihisar that it was as high as 1.9 m and penetrated 1.3 km in Sigacik. Its moment magnitude is 7.0 (GCMT) and caused the loss of lives in the Izmir-Bayrakli district, with many wounded. We used 34 vertical acceleration seismograms to calculate Mwp. Table 2 shows the used stations and calculated Mwp for each seismic station with an average. Hence, we found that Mwp is 7.0 with an average value. Figure 3 shows the change in Mpw with epicentral distance.

Table 2. Used stations with calculated Mwp for event 1

Station	**Distance (km)**	**Mwp**	**Station**	**Distance (km)**	**Mwp**
3536	50.44	6.8	3522	87.72	7.0
0905	52.69	6.5	3513	88.51	6.9
0911	62.64	7.1	3511	89.13	7.3
3523	63.57	7.0	3514	89.88	7.4
0920	65.19	6.0	3524	89.97	7.2
3528	66.13	6.5	0922	91.14	7.5
0918	67.39	6.7	4823	92.16	6.6
3533	67.89	7.4	3520	92.31	7.2
3516	70.25	7.0	4822	92.33	6.5
3538	73.22	7.4	3526	94.53	7.0
3506	78.76	6.8	4814	95.12	6.6
0921	81.32	7.2	3527	98.66	6.9
3517	81.86	7.2	3539	99.10	7.1
3512	82.30	7.3	4817	99.96	6.4
3518	84.87	7.5	3534	100.4	6.4
3519	85.66	7.5	0919	104.36	7.1
3521	85.92	6.7		**Mean Mwp**	**7.0**

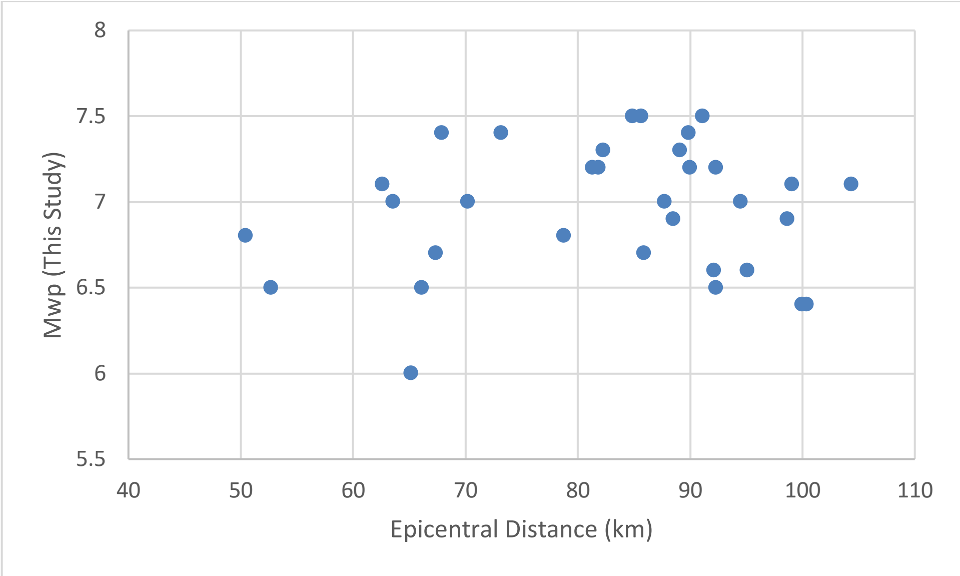

Figure 3. The change of calculated Mwp magnitude with epicentral distance for event 1

3.2. Event 2 (2021/10/12, Crete, Greece)

Event 2 occurred in the Mediterranean around Crete Island. The epicentre region had large earthquakes in the historical era. We used 17 vertical acceleration seismograms to calculate Mwp. Table 3 shows the used stations and calculated Mwp for each seismic station with an average. Mwp is calculated as 6.6, and Figure 4 shows the change in Mwp with epicentral distance.

Table 3. Used stations with calculated Mwp for event 2

Station	Distance (km)	Mwp	Station	Distance (km)	Mwp
4812	222.24	6.8	4808	290.04	6.8
4809	244.34	6.3	4807	301.85	6.5
4819	266.01	6.7	0919	311.32	6.6
4817	271.64	6.3	0905	326.85	6.6
4806	284.27	6.7	4818	322.48	6.7
4814	288.71	6.7	0921	336.86	6.4
4823	293.51	6.8	0922	337.92	6.7
4822	293.51	6.8	4820	321.05	6.5
0920	298.23	6.5		**Mean Mwp**	**6.6**

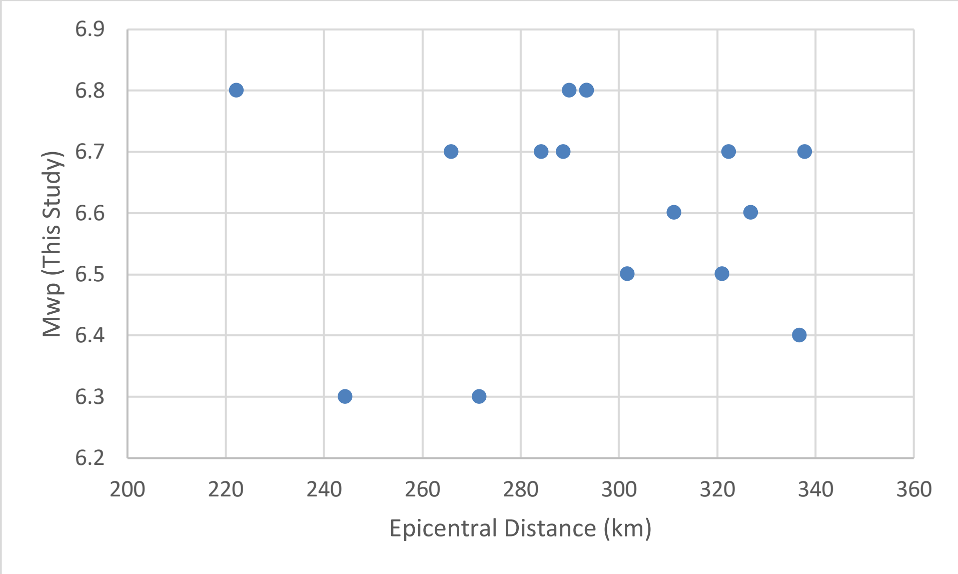

Figure 4. The change of calculated Mwp magnitude with epicentral distance for event 2

3.3. Event 3 (2022/01/11, Cyprus Region)

Event 3 occurred in the Mediterranean around Cyprus Island. We used 19 vertical acceleration seismograms to calculate Mwp. Table 4 shows the used stations and calculated Mwp for each seismic station with an average. Mwp is calculated as 6.6 and Figure 5 shows the change in Mwp with epicentral distance.

Table 4. Used stations with calculated Mwp for event 3

Station	Distance (km)	Mwp	Station	Distance (km)	Mwp
99001	99.23	6.9	0714	188.29	6.7
99003	120.26	6.8	99007	228.78	6.2
99004	120.45	6.7	0710	215.50	6.8
99013	145.23	6.3	3306	246.98	6.9
99012	147.61	6.6	0706	223.28	6.0
99005	149.31	6.9	0712	218.83	6.4
3307	165.53	6.6	0711	236.32	6.8
GAZI	159.14	6.9	4211	260.60	6.9
0718	162.32	7.0	0717	253.06	6.7
99008	195.45	6.1		**Mean Mwp**	**6.6**

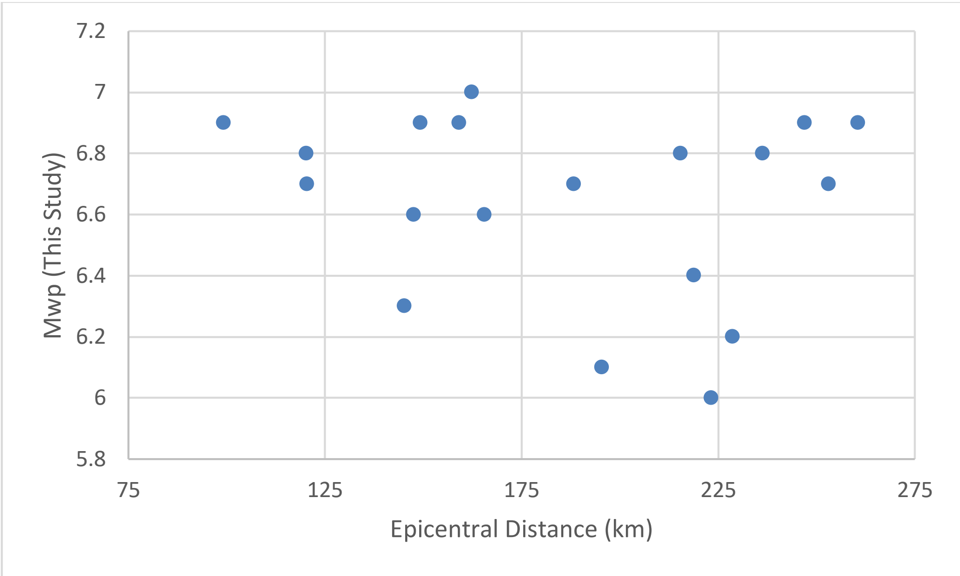

Figure 5. The change of calculated Mwp magnitude with epicentral distance for event 3

4. Discussion

This study aimed to test the success of strong-motion records in calculating the Mwp to understand its usefulness for early warning issues. The underestimation problem of some magnitude types, such as local magnitude (ML) and body-wave magnitude (mb), should be remembered for earthquakes that have a magnitude greater than 6.5. For the early warning issues, the main problem is to calculate the magnitude as much as correctly in a short time. Estimating it in some tens of seconds is possible using strong motion records. The main problem is the unknown source time for selecting the correct calculation window. Therefore, this study focused on only strong motion records because the three seconds time window is enough for calculations. The Mwp at some stations is lower than the mean, whereas at some higher. The soil structure beneath the seismic recorder causes one possibility. Moreover, this study implies that strong motion records to locate the events and determine the magnitude will also be helpful in increasing the azimuthal coverage.

The paper focuses on the rapid moment magnitude estimation using strong motion records. Its advantage is related to clipping that can be seen on velocity records with too short epicentral distances. The attenuation relationship has not been considered for the present study. The present paper could not propose how early warning systems use this technique because it has not focused on any specific early warning system in and around Turkey. We suggested the results of a test of rapid magnitude technique with strong motion records that are very new in the magnitude calculations. The study shows that this technique can be used to determine the earthquakes have a magnitude greater than 6.5. Moreover, if the strong motion seismic stations have smaller than a hundred km epicentral distances, the calculation time will be around a maximum of twenty seconds.

5. Conclusions

We calculated the P-wave moment magnitude using strong-motion records for the tsunamigenic-sourced earthquakes in the Mediterranean and Aegean Seas. The magnitude difference is about 0.2 units with GCMT (Figure 6), but it could be negligible considering the calculation time that measurable in seconds which is the main task of this study. The study showed that strong motion records are so practical for calculating the Mwp quickly for an early warning or any rapid response action.

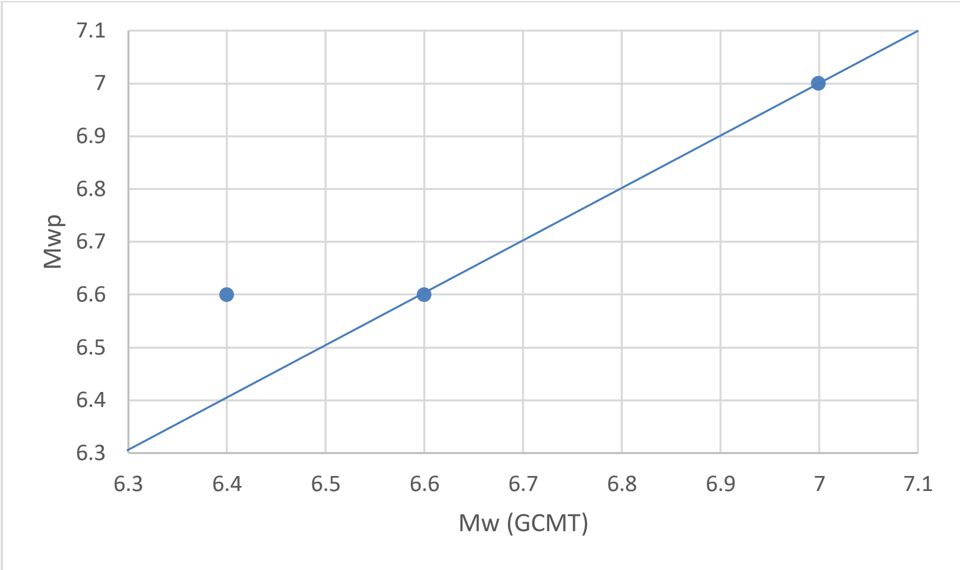

Figure 6. The deficit between Mwp (this study) and Mw (GCMT) for the three events

Acknowledgements

Thanks to AFAD for seismic data, we used GMT (Generic Mapping Tools) by Wessel and Smith [18] to generate the figures.

Conflict of Interest

The authors reported no potential conflict of interest.

Author Contributions

The data collection and analysis were performed by Timur Tezel. All authors contributed to interpreting the results and writing the manuscript.

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