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Rapid Determination of Earthquake Magnitude Using Measurements of the Dominant Period of P-Waves Observed at Local Stations in North Sulawesi

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This research aims to examine basic physics principles and mechanisms of determining local earthquake magnitude Mpd observed at local seismic stations in North Sulawesi and its surroundings using rapid calculations of the dominant period from P-waveforms with the help of JokoTingkir, a package program used for this issue. The data used were secondary, downloaded from Webdc3 in the form of magnitudes scaled with MW in North Sulawesi during 2010–2015 with all events were sea-hypocentered. The study focuses on estimates of a local earthquake size as a primary parameter in seismic studies and surveillance via a linear equation relating the dominant period Td to the earthquake size MW. When this equation was inverted an empirical formula was then obtained, $\mathrm{Mpd} = (\mathrm{Td} + 7.7536)/1.7018$ for North Sulawesi and its nearby regions. The formula was used to recalculate events having small to moderate magnitudes that occurred in the region of interest from 2010 to 2015. The results were then compared to those of reference MWCMT provided by the Global CMT catalog with a standard deviation of the scatter of only 0.2 was found, in very good agreement with previous work. We conclude that there is no significant difference in magnitude between values derived from the method proposed in the present study and those given by the Global CMT catalog for the reference of magnitude. The results are discussed in terms of rapidness and accuracy of earthquake magnitude determination required for use of hazard mitigation.

Keywords: Local Earthquake Magnitude, Dominant Period, Empirical Formula, North Sulawesi.

1. INTRODUCTION

In response to practical needs for seismic studies and surveillance, rapid determination of earthquake magnitude is a crucial point. This comes along with knowledge of an earthquake size obtained from immediate assessment of the event, allowing us to compare a particular event to another,[2] to estimate possibly destructive impacts on the surrounding structures,[12] and to reduce possibly disaster risks on lives and properties in the context of earthquake early warning system.[11] However, magnitude determination brings some consequences to experts in the field in the sense that the size released to the public must certainly be short in time and accurate in magnitude because rapidness and accuracy of earthquake analyses are required for use of disaster risk reduction efforts.[10]

Difficulties in rapid and accurate determination of earthquake magnitudes have long led many physicists and seismologists to propose methods of determining the earthquake size rapidly and accurately using various techniques possible.

An existing method of earthquake magnitude determination may have utilized a local magnitude method, known as ML, currently used by the Indonesian Agency for Geophysics, Climatology, and Meteorology (BMKG) for monitoring earthquake-related disasters. However, this method has lack of accuracy when applied to events with magnitudes ≥ 6.0 as demonstrated by McCalpin.[9] A more accurate method is a moment magnitude method, written as MW, used for earthquakes ranging from small to large sizes but it requires a relatively long time to complete the process for a reliable early warning system. Lomax and Michelini[3] proposed direct procedures to rapidly determine an earthquake size, termed as MWpd, within 20 minutes after main shocks, using measurements of rupture duration recorded at

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remote stations. In the light of searching for an effective tsunami early warning system, a method to include the dominant period of P-wave first arrivals along with other relevant parameters[4–6] was introduced to reduce inaccuracy in tsunami warnings issued, as well as to shorten calculation processes to only within several minutes. This was followed by the development of JokoTingkir programming codes designed for better assessment of events in terms of increased reduction in false warnings that may occur in future times in Indonesia.[7]

Another method of magnitude determination has then explored measurements of the dominant period, particularly when dealing with local events. Shieh et al.[12] studied a number of cases with large amplitudes that occurred in Japan using an empirical formula relating the dominant periods of first seismic signals arrived at local stations to its magnitudes, with a small standard deviation of approximately 0.2 was obtained for the datasets used. This gives shed light on the use of local parameters including magnitudes recorded at nearby stations. In this context, the present study aims to examine mechanisms of determining local earthquake magnitude, named here as Mpd, observed at local stations in North Sulawesi using rapid calculation of the dominant period Td extracted from P-wavelets. The specific aim of this study is to search for a reliable method of quick magnitude estimates of local events in the region of interest in order to minimize fatal deaths and injuries, and damage potential leading to property losses within the context of hazard mitigation.

2. METHODOLOGY

A total of 72 local earthquake events with hypocenters below the sea surface at depth and magnitudes in the range $4.0 \leq M \leq 7.5$ that occurred in North Sulawesi during a time period of 2010–2015 years were used as the data in this study, where

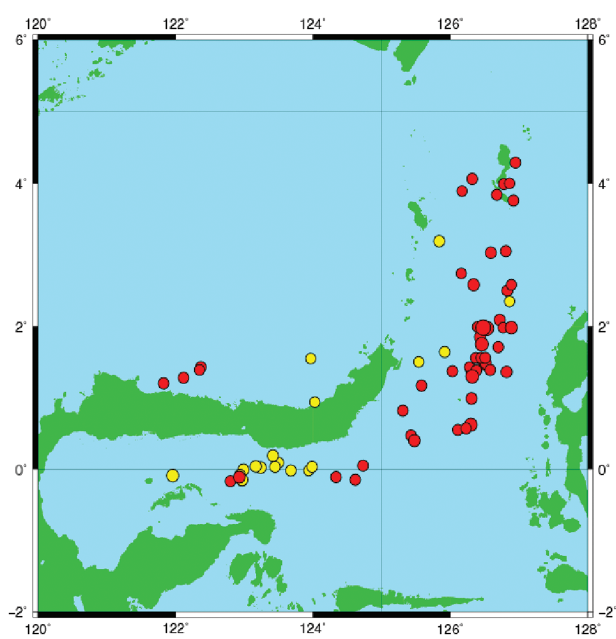

Fig. 1. Map of all the earthquake events occurring in North Sulawesi during 2010–2015 examined in this study, where red full-circles represent sources at shallow depths with hypocenters ≤100 km and yellow full-circles represent the ones at mid depths with hypocenters located between 100 km and 300 km from the surface.

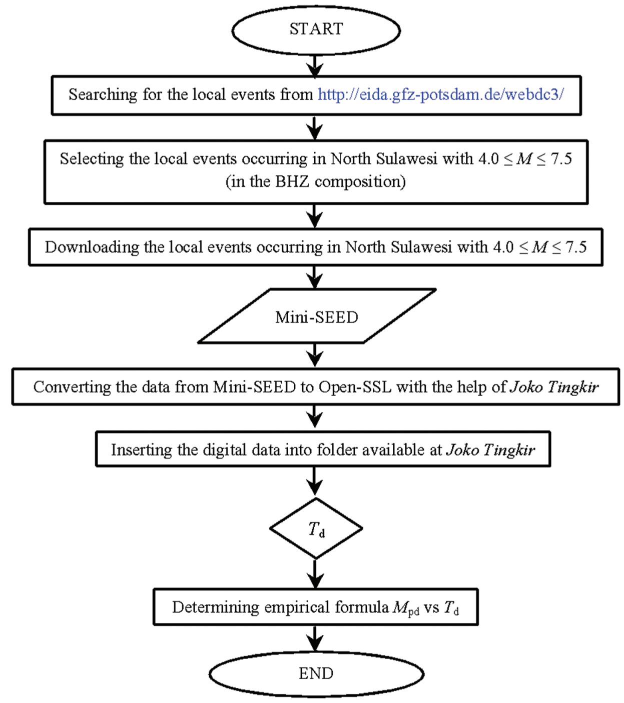

Fig. 2. Simple flowchart, showing data collecting and analyses for all events considered in this study.

area of interest is positioned along 0.250–5.570 N and 123.120–127.170 E (see Fig. 1).

All the events were freely downloaded as broadband seismograms from two sites: http://eida.gfz-potsdam.de/webdc3/ and http://www.globalcmt.org/ and analyzed using SeisGram2K, available at http://alomax.free.fr/seisgram/SeisGram2K.html to obtain digitalized data necessary for the vertical component of P-waves. All magnitudes obtained from the Webdc3 site were named as MW whereas those from the Global CMT site were termed as MWCMT for direct comparison between the two before deciding which one was used for rapid calculations of Td. Regarding insignificant differences in magnitude between MW and MWCMT, we then used the former in rapidly calculating Td using JokoTingkir and keep MWCMT being the reference to which all magnitude estimates of the local occurrences reported here as Mpd are relatively compared. The estimates were determined by an empirical formula, derived from an inverted linear equation relating Td to MW. Thus, we would like to see if there is agreement between rapid determination of magnitudes of the local earthquakes for moderate events in majority using the method proposed in the current study and magnitudes of the same events provided by the Global CMT catalog.

Figure 2 describes a flowchart for techniques performed to collect and analyze the data used in the present study.

3. RESULTS AND DISCUSSION

Estimates of earthquake magnitudes with all the 72 shallow, local occurrences are sea-hypocentered at some depth observed by a network of local stations in North Sulawesi during 2010–2015 are measured as MW (collected from Webdc3) and MWCMT (collected from the Global CMT), respectively. Using these data, we found that in average for each measure $\text{MW} \approx 5.2$ and

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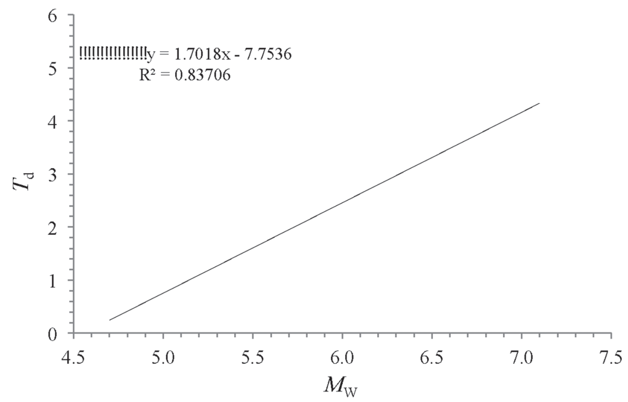

Fig. 3. Plot of all the local events shown in red full-circles occurring in North Sulawesi during 2010–2015 for cases where $4.0 \leq M \leq 7.5$, showing a linear relationship between Td measured in seconds and MW with a line of regression and its corresponding linear equation shown inside the box.

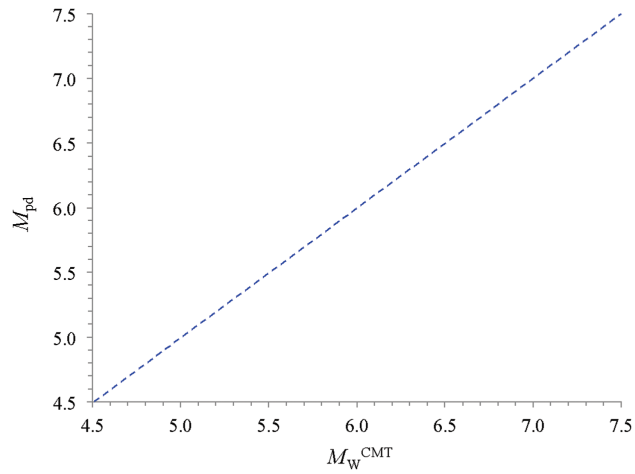

Fig. 4. Plot of all the local events occurring in North Sulawesi during 2010–2015 scaled with two different methods, demonstrating good consistency between values of Mpd measured by the current method and those of MWCMT provided by the Global CMT catalog.

MWCMT $\approx$ 5.3 leading to a small standard deviation of only 0.2. This allows us to calculate Td quickly using either a value scaled with MW or MWCMT with no significant difference in the result of calculation. Here we provide plot of Td with respect to MW in Figure 3.

It should be noted that with a correlation coefficient $R \approx 0.92$ (directly derived from $R^2 \approx 0.84$) the regression line shows a linear dependence of Td upon MW with no doubt. When this linear equation is inverted, an empirical formula for estimating earthquake sizes in the region of interest is then obtained in the form

$$\text{Mpd} = (\text{Td} + 7.7536)/1.7018 \quad (1)$$

where we have replaced MW with Mpd for relevance in the sense that the exact formula is much influenced by site effects through a pair of a constant and a coefficient, as also indicated in the work of Shieh et al.[12] and in a conference paper—unpublished work—made by Gunawan et al. (2011).

From all the local occurrences examined in the present study, the sizes calculated using Eq. (1) are consistent with values given by both Webdc3 and the Global CMT catalog measured here as MW and MWCMT. In comparison to MWCMT as magnitude reference, a relatively small standard deviation of approximately 0.2 was found for all magnitudes obtained using the method proposed in the present study. The same standard deviation was also obtained when the current results are compared to those measured in MW. It follows that magnitudes Mpd of local events estimated using Eq. (1) can thus be, to the first order, used to predict an earthquake size, if the Td data are given or rapidly calculated first, in North Sulawesi with some caution when a particular local event may strike the region in the future. Figure 4 describes direct comparison between the results of magnitude determination using the present method and those given by the Global CMT catalog.

The standard deviation for both methods of magnitude measurements is of 0.2. Red full-circles describe the scatter for cases where $4.0 \leq M \leq 7.5$, with those placed in the blue dashed-line representing the same size of the occurrences observed by the two methods.

It is clear that Figure 4 shows accurate estimates of local occurrence magnitudes Mpd in North Sulawesi for a time period of 2010–2015, particularly for events having magnitudes $\leq$6.5 measured as MWCMT. The magnitude estimates are directly determined from Eq. (1) with the help of rapid calculation of the dominant period Td. Considering that there is only a small value of 0.2 for standard deviation of the random data found between the two methods of magnitude determination, we suggest that the present method is worth to be applied in cases where earthquake events occur and are recorded by local seismic stations nearby within a distance of no more than 1100 kilometers away from the earthquake epicenter. In terms of insignificant difference in the calculated magnitudes between values estimated using the proposed method in this study and those of the reference available at the site of the Global CMT catalog, the results are in very consistent with previous work.[2,3,12] However, for 3 events having magnitudes $\geq$6.5 (see the 3 red circles on top right of Fig. 3), the current method over estimates the earthquake sizes, relatively compared to values given by the magnitude reference MWCMT. At this stage, we could not say further for this but arguing for lack of datasets in a time period of years examined with large sizes in magnitude.

Problems in determining earthquake magnitude quickly and accurately have been an important issue for years. Many researchers have since then utilized various procedures and techniques to better estimate the size. Two key aspects of importance in magnitude determination are rapidness and accuracy.[5,7,8,12] Although the present results for the datasets used in this study are limited by the influence of local parameters, the method proposed is, to some extent, worth to test further by applying it to different areas of research in the Indonesian archipelago. In particular, when we are facing with possible earthquake events recorded at a network of local seismic stations owing to a high level of seismic activities in some regions of the country this method developed for better use of determining the size rapidly and accurately may therefore provide better prediction. As pointed out by Baeda,[1] there has currently been a positive trend especially in North Sulawesi and its perimeter for occurrences with shifted hypocenters from lands to seas at depth, and hence people in the regions are possibly affected by major earthquake-induced disasters. It follows that research in quantifying earthquake sizes rapidly and accurately for minimizing unexpected victims remains becoming an important issue in the context of disaster risk reduction efforts.

4. CONCLUSIONS

Rapid and accurate magnitude determination of earthquakes are of fundamental importance in reducing possible destruction to a minimum level. In particular, when dealing with local events we may better predict the sizes Mpd using knowledge of the dominant period Td of P-waves that is quickly calculated by JokoTingkir codes. The method developed for cases occurring in North Sulawesi during 2010–2015 with magnitudes in the range $4.0 \leq M \leq 7.5$ used in this study provides an alternative solution to the magnitude determination. Using the datasets freely downloaded from the Webdc3, the results for all the cases considered lead to the empirical formula $\mathrm{Mpd} = (\mathrm{Td} + 7.7536)/1.7018$. Magnitude reconstruction of all the occurrences using this formula yields insignificant differences in sizes between values estimated by the method in the present study and those given by the Global CMT catalog with a small standard deviation of only 0.2, less than 4% relatively compared to the mean magnitude of approximately 5.3 of the datasets used. Regarding this, the current study is in very good agreement with previous work.[2,3,12]

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References and Notes

1. A. Y. Baeda, *J. Inter. Develop. Coop.* 17, 17 **(2011)**.
2. G. Di Grazia, H. Langer, A. Ursino, L. Scarfi, and S. Gresta, *Ann. Di Geof.* 44, 579 **(2001)**.
3. A. Lomax and A. Michelini, *Geophys. J. Inter.* 176, 200 **(2009)**.
4. A. Lomax and A. Michelini, *Geophys. J. Inter.* 185, 283 **(2011)**.
5. A. Lomax and A. Michelini, *Pure. App. Geophys.* **(2012)**, DOI: 10.1007/s00024-012-0512-6.
6. Madlazim, *Sci. Tsu. Haz.* 32, 29 **(2010)**.
7. Madlazim, T. Prastowo, and T. Hardy, *Sci. Tsu. Haz.* 34, 189 **(2015)**.
8. Madlazim and T. Prastowo, *Earth Sci.* 29, 27 **(2016)**.
9. J. P. McCalpin, Appendix 1: Earthquake Magnitude Scales, GEO-HAZ Consulting Inc., Crestone, Colorado 81131, USA **(2010)**.
10. K. Satake, *Geosci. Let.* 1, 1 **(2014)**.
11. C. Satriano, Y. M. Wu, A. Zollo, and H. Kanamori, *Soil. Dyn. Earth Eng.* **(2011)**, DOI: 10.1016/j.soildyn.2010.07.007.
12. J. T. Shieh, Y. M. Wu, and R. M. Allen, *Geophys. Res. Let.* 35, 1 **(2008)**.

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