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DEVELOPMENT OF TSUNAMI EARLY WARNING APPLICATION FOUR MINUTES AFTER AN EARTHQUAKE

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ABSTRACT

Effective early warning at local to regional distances is maximum 10 minutes after the OT. The shorter the tsunami early warning time that is announced, of course, the more time the community will have to prepare for mitigating the disaster. The purpose of this study is to develop a tsunami application and show the current real-time data available in most tsunami hazard areas in Indonesia - in particular, earthquake location, magnitude and tsunami discriminant Td, T50Ex, T0, Td x T50, and Td x T0 can be determined about four minutes after the earthquake occurs. This process will be implemented and continues in real-time in earthquake monitoring and tsunami early warning installed by the Meteorology Climatology and Geophysics Council. The availability of this rapid tsunami application (about 4 minutes after the OT) can help in tsunami early warning that is faster and more reliable for short distances to areas that have the potential of having the a tsunami impact. The purpose of this study is to produce a tsunami early warning application 4 minutes after the earthquake. The research method used in this study is the ADDIE development method (Analysis, Design, Development, Implementation and Evaluation). In the first year, the focus of the development of rapid tsunami early warning applications was about 4 minutes after the OT. Our previous research results have supported a lot of development this application and make it easier for us to complete the prototype target, it has been obtained the results of the tsunami application prototype 4 minutes after the OT which is currently being tested in real time at the Meteorology Climatology and Geophysics Council Research and Development Center in Jakarta, Indonesia.

Keywords: *tsunami parameters; tsunami early warning; tsunami early warning application; 4 minutes after the earthquake*

1. **INTRODUCTON**

The most destructive tsunamis at close range tsunami-affected areas (eg <1000km) from the epicenter of the earthquake, arrive within 20-30 minutes after the earthquake (OT); Effective early warning at this distance requires notification in less than 10 minutes after OT (eg, Tsushima et al., 2011; Newman et al., 2011; Madlazim, 2011). At present, a rapid assessment of the tsunami potential from earthquake by organizations such as the Meteorology, Climatology and Geophysics Agency (BMKG), Japan Meteorological Agency (JMA), German-Indonesian tsunami warning system (GITEWS) or West Coast and Alaska (WCATWC) and the Pacific (PTWC) depend mainly on the initial estimate of the earthquake location, depth and moment, M0, or the corresponding moment magnitude, Mw. However, reliable Mw calculations for large earthquakes are usually provided by CMT by the tensor-moment tensor power, Mw (Ekström et al., 2005), which requires inversion of waveforms, varying with rupture depth, earth model and other factors, and only available 20-30 minutes or more after an earthquake occurs (Hayes et al., 2011; Duputel et al., 2011). Therefore, fast magnitude estimators such as MWp are used for tsunami CMT warnings, but the Mwp performs poorly compared to Mw and other discriminants for tsunami potential (Lomax and Michelini, 2011A, LM2011; Madlazim, 2011).

To produce effective and efficient tsunami early warning, especially for short distances to potentially tsunami affected areas, we use the tsunami parameter calculation method quickly. We have presented (Lomax and Michelini, 2009B; LM2011; Lomax and Michelini, 2011B; Madlazim, 2011; Madlazim 2013) direct procedures for rapid assessment of potential tsunami earthquake by using direct methods, it is not the inversion of treatment steps on P-wave seismograms - Td dominant period, more than 50 minutes duration, T50Ex, rupture duration, T0. T0 for large earthquakes is mainly related to the length of the rupture, L, and both Td and T0 will increase, the depth of rupture, z, decreases, because the effects of shear modulus and rupture speed, vr are reduced. We have shown (Madlazim 2011; Madlazim 2013) that product multiplication duration Td x T0 or Td x T50Ex provides more information about the impact of tsunami than the Mw, Mwp, Mwpd discriminant (Lomax and Michelini, 2009A, LM2009A; Madlazim. 2011; Madlazim 2013), and other currently used discriminants. These results indicate that the tsunami potential is not directly related to the product L x W x D of the "seismic" fault model, as assumed by the use of Mw discriminant so far and suggest that information about length and depth can explain the tsunami potential of an earthquake well. Information about the rupture's length and depth is provided by TD x T0 and Td x T50Ex, where explicit estimation of the rupture's length and depth are difficult and cannot be determined quickly.

Until today, the earthquake and tsunami early warnings continue to be developed to get a more accurate and faster earthquake and tsunami early warning system. Effective tsunami early warning for coastlines at regional distances (> 500 km) from the epicenter of the earthquake that creates a tsunami requires notification within 15 minutes after the earthquake. Recently, through analysis of P-wave tele-seismic seismograms (30º-90º, GCD), Lomax and Michelini (2009) have shown that the frequency is high, the duration of rupture, T0, is greater than about 50 or T0 is greater (65) (Madlazim 2011 ; Madlazim, 2013 Madlazim et al., 2015), strengthens the accuracy of tsunami early warning. Lomax and Michelini (2009) exploit this result through direct "duration-exceedance" (DE) procedures applied to seismograms on GCD

10-30º to determine quickly whether T0 for earthquakes tends to exceed 50-55 s and thus become a potentially tsunami earthquake. Madlazim et al., (2015) implemented the Lomax and Michelini (2009) teleseismic method to measure T0 and T50Ex (DE) with a 65-second threshold for T0, 1 for T50Ex and 10 seconds for the dominant period (Td).

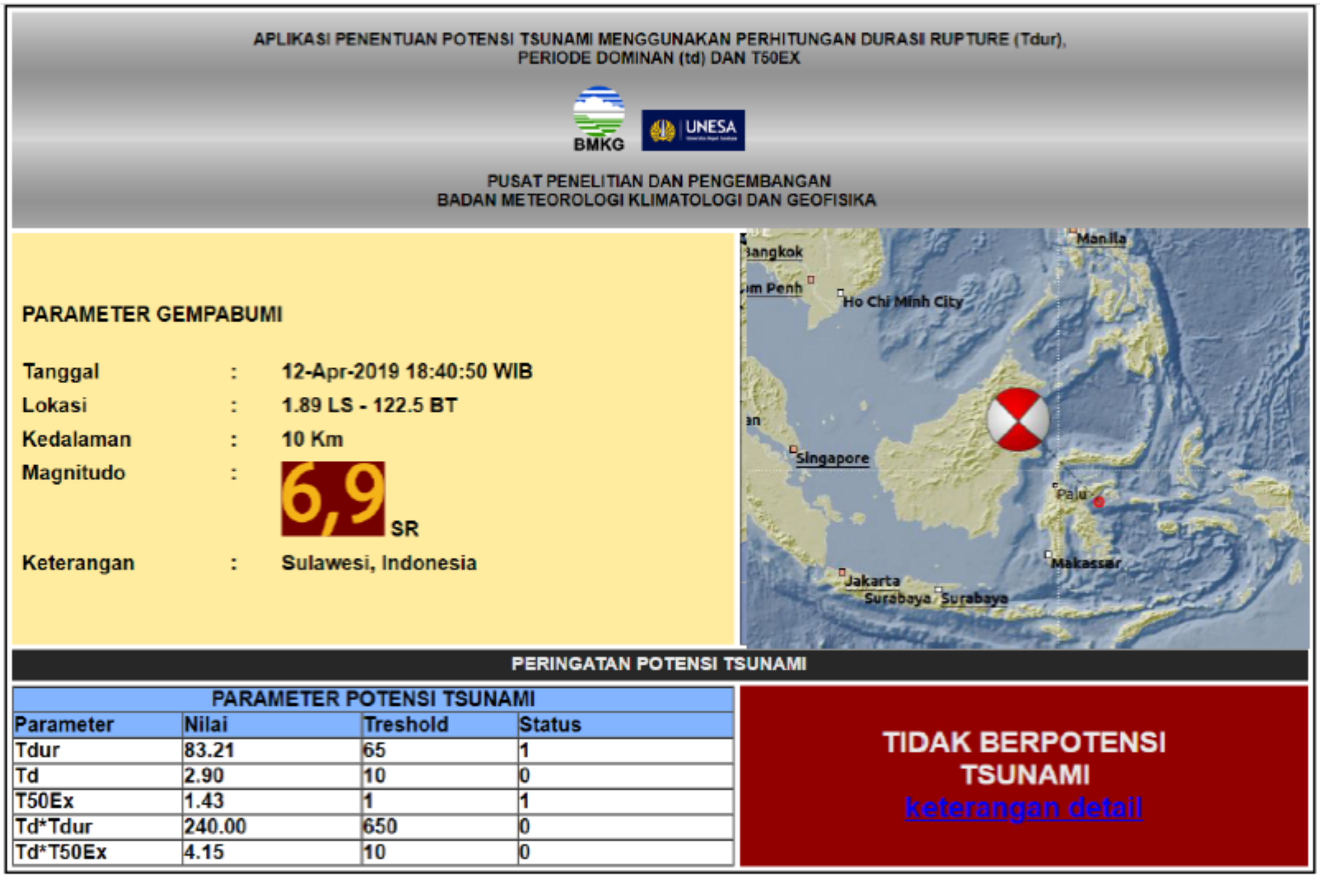
2. METHODS

To achieve the objectives of this study the ADDIE model (Aldoobie, 2015) is used, which consists of 5 stages; Phase of Analysis, Design, Develop, Implementation and Evaluation. The first stage is the Analysis stage. After this stage is completed, then the results are evaluated. The second stage is the Design stage. After this stage is completed, then the results are evaluated. The third stage is the Develop stage. After this stage is completed, then the results are evaluated. The fourth stage is the Implementation stage. After this stage is completed, then the results are evaluated. The fifth stage is the Evaluation stage. This evaluation phase is carried out for all stages.

The five stages in this ADDIE model are as follows: **1. Analysis Phase;** the main activity is to analyze the need to develop a Tsunami Early Warning Application about 4 minutes after the Origin Time of the Earthquake and analyze the feasibility and requirements for developing the application. The existence of problems in the system that have been implemented is not relevant to the needs of the target, technology, and the availability of real-time seismogram data. **2. Designing Phase.** The designing phase is the activity of designing a Tsunami Early Warning Application about 4 Minutes after the Origin Time of the Earthquake. The design of this application is still conceptual and will underlie the next development process. **3. Development Phase**. The Development phase contains the realization of product's design activities. The conceptual framework of the Tsunami Early Warning Application of around 4 Minutes after the Origin Time of the Earthquake is compiled and realized into a product that is ready to be implemented. For example, in the designing phase, the designed application is still conceptual, so that at the development stage, the application and the device are made to be ready to be implemented. **4. Implementation Phase.** At this stage, the Tsunami Early Warning Application after 4 Minutes of the Origin Time of the Earthquake is implemented in a real and relevant situation (Meteorology Climatology and Geophysics Council) and an initial evaluation is carried out to provide feedback on the next application. The used real-time data to estimate the earthquake and tsunami parameters is taken from data recorded by a network of local seismic stations managed by the Meteorology Climatology and Geophysics Council. The implementation process for determining tsunami parameters has been integrated with the Indonesian Tsunami Early Warning System known as InaTews (Madlazim, Prastowo, and Hardy 2015). **5. Evaluation Stage.** The Evaluation phase this is done at the processing stage and at the end of the activity. Each end of the stage is evaluated and at the end of the previous four stages, an evaluation is also carried out. Revisions are made according to the evaluation results or needs that cannot be fulfilled by the application yet.

3. RESULTS AND DISCUSSION

The results of this development study can be divided into 2, namely the results in the form of a tsunami early warning application 4 minutes after the earthquake's origin time whose output is presented in Figure 1 and Figure 3 and the results of the application's appropriateness. The output of tsunami early warning application 4 minutes after the earthquake's origin time is in Figure 1 below. In the example of the output of the tsunami early warning application new version is an additional display of the earthquake focal mechanisms that are determined in real time. The focal mechanism can be used as one of the additional information for consideration in making decisions about the potential of a tsunami generated by an earthquake.



APLIKASI PENENTUAN POTENSI TSUNAMI MENGGUNAKAN PERHITUNGAN DURASI RUPTURE (Tdur),
PERIODE DOMINAN (td) DAN T50EX

BMKG
UNESA

PUSAT PENELITIAN DAN PENGEMBANGAN
BADAN METEOROLOGI KLIMATOLOGI DAN GEOFISIKA

PARAMETER GEMPABUMI

Tanggal : 12-Apr-2019 18:40:50 WIB
Lokasi : 1.89 LS - 122.5 BT
Kedalaman : 10 Km
Magnitudo : 6,9 SR
Keterangan : Sulawesi, Indonesia

PERINGATAN POTENSI TSUNAMI

PARAMETER POTENSI TSUNAMI			
Parameter	Nilai	Treshold	Status
Tdur	83.21	65	1
Td	2.90	10	0
T50Ex	1.43	1	1
Td*Tdur	240.00	650	0
Td*T50Ex	4.15	10	0

TIDAK BERPOTENSI
TSUNAMI
keterangan detail

Figure 1. Examples of output from the Tsunami Application 4 minutes after the earthquake equipped with a focal mechanism for August 12th, 2019 earthquake and there is NO TSUNAMI POTENTIAL

The determination of focal mechanism in real time by using the HASH 1.2 method can be accessed free on the web https://earthquake.usgs.gov/research/software/#HASH. To determine the focal mechanism of an earthquake, it takes UP or DOWN data from first motion, phase data, epicentral distance data, take-off beam and azimuth angle from each of Indonesia's local seismic stations managed by Meteorology Climatology and Geophysics Council. Then, by setting the control file, the focal mechanism can be determined. For example, the output is the earthquake focal mechanism that occurred on the Sulawesi Sea on 12th of April 2019 with magnitude 6.9 as shown in Figure 1. From the 5 tsunami parameters, only two tsunami parameters have slightly exceeded the threshold of Tdur and T50Ex. Whereas the other 3 tsunami parameters (Td, Td * T50Ex and Td * Tdur) do not exceed the threshold, so the tsunami early warning application 4 minutes after the origin time decides there is NO TSUNAMI POTENTIAL. Clearly, the earthquake focal mechanism was strike-slip. Focal earthquake strike-slip mechanism can also cause tsunami (Tanioka and Satake 1996). The output of the focal mechanism from the April 12th, 2019 earthquake has been confirmed by the focal mechanism for the same earthquake in the GLOBAL CMT catalogue (https://www.globalcmt.org/CMTsearch.html) and the results are almost no significant difference. Therefore, the addition of the focal mechanism display in the application of early warning 4 minutes after the origin time further adds to the accuracy of the tsunami application. This application provides information certainty faster (about 4 minutes after origin time), whether an earthquake causes a tsunami or not, so that if needed, a mitigation or evacuation process can be prepared and carried out immediately.

The test of the tsunami early warning application in Palu on 28th of September 2018 was carried out in real-time, also by using local seismic stations as shown in figure 2 to determine tsunami parameters for the September 28th 2018 earthquake.

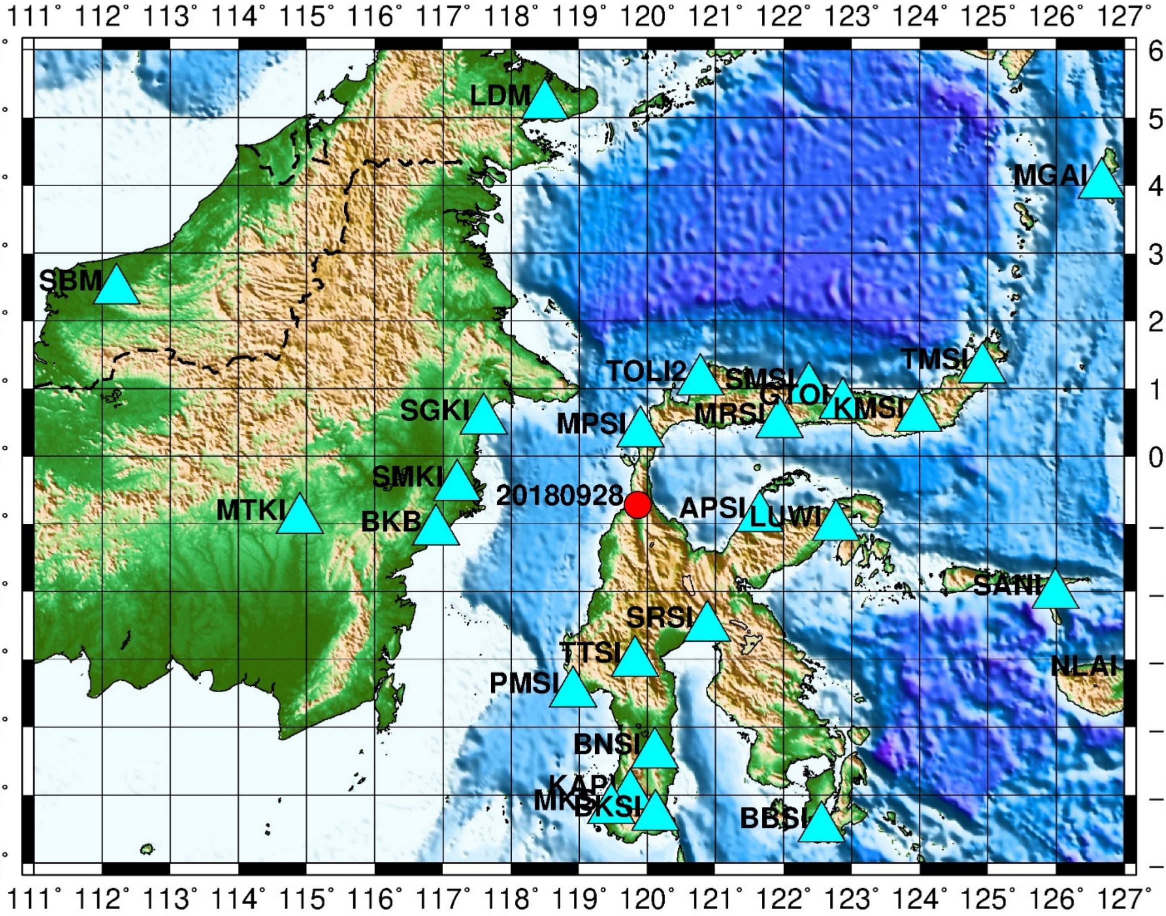
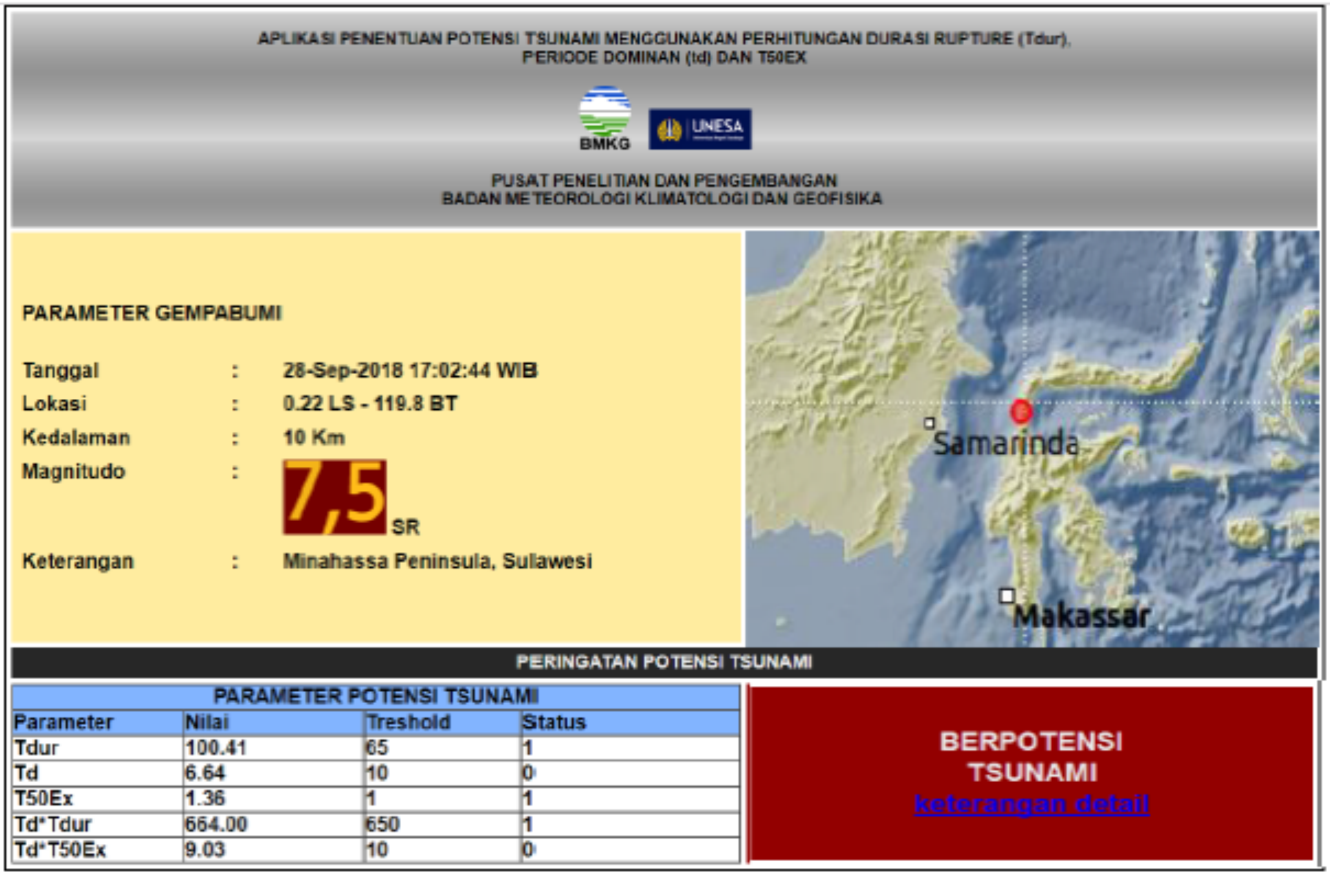


Figure 2. Distribution of the local seismic station (cyan triangle) used by the tsunami application to determine the parameters of the tsunami earthquake in Palu, Indonesia on September 28th, 2018 with the earthquake epicenter (red points).

The use of local stations as shown in Figure 2 allows the results of measuring tsunami parameters (Tdur, Td, and T50Ex) to become available and be announced before 4 minutes, after the origin time of the earthquake. To maintain the accuracy of the measurement results of the tsunami parameters, M-filters were installed (Madlazim et al. 2018). The results of the pilot prototype of the tsunami early warning application 4 minutes after the earthquake in real time for the last 300 earthquakes that occurred in Indonesia (Fig. 4), did not occur in any false warnings.



APLIKASI PENENTUAN POTENSI TSUNAMI MENGGUNAKAN PERHITUNGAN DURASI RUPTURE (Tdur), PERIODE DOMINAN (td) DAN T50EX

PUSAT PENELITIAN DAN PENGEMBANGAN
BADAN METEOROLOGI KLIMATOLOGI DAN GEOFISIKA

PARAMETER GEMPABUMI

Tanggal	:	28-Sep-2018 17:02:44 WIB
Lokasi	:	0.22 LS - 119.8 BT
Kedalaman	:	10 Km
Magnitudo	:	7,5 SR
Keterangan	:	Minahassa Peninsula, Sulawesi

PERINGATAN POTENSI TSUNAMI

PARAMETER POTENSI TSUNAMI

Parameter	Nilai	Treshold	Status
Tdur	100.41	65	1
Td	6.64	10	0
T50Ex	1.36	1	1
Td*Tdur	664.00	650	1
Td*T50Ex	9.03	10	0

BERPOTENSI
TSUNAMI
keterangan detail

Figure 3. Output of the tsunami early warning application 4 minutes after the earthquake for an earthquake in Palu Indonesia on September 28th, 2018 and there is a TSUNAMI POTENTIAL

The last 300 earthquakes are used for testing the tsunami early warning applications 4 minutes after the earthquake (the yellow epicenter) that occurred in Indonesia starting on June 12th, 2018 until July 20th, 2019 with the magnitude of the earthquakes ranging from 4 to 7.5. The distribution of the earthquake epicenter is presented in Figure 4 as follows.

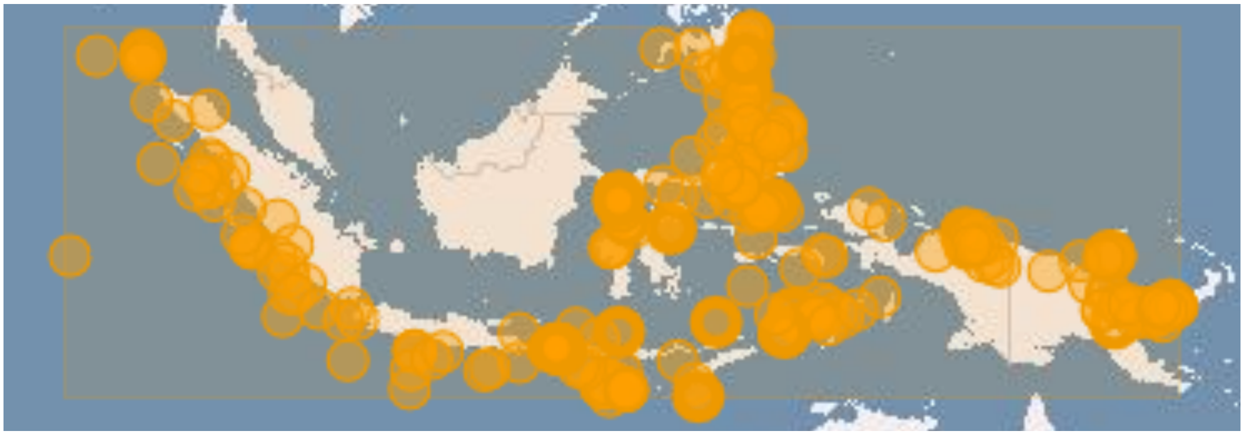


Figure 4. Distribution of earthquake epicenters that occurred in Indonesia from 12th of June 2018 to 20th of July 2019 which are used for testing tsunami applications 4 minutes after the earthquake.

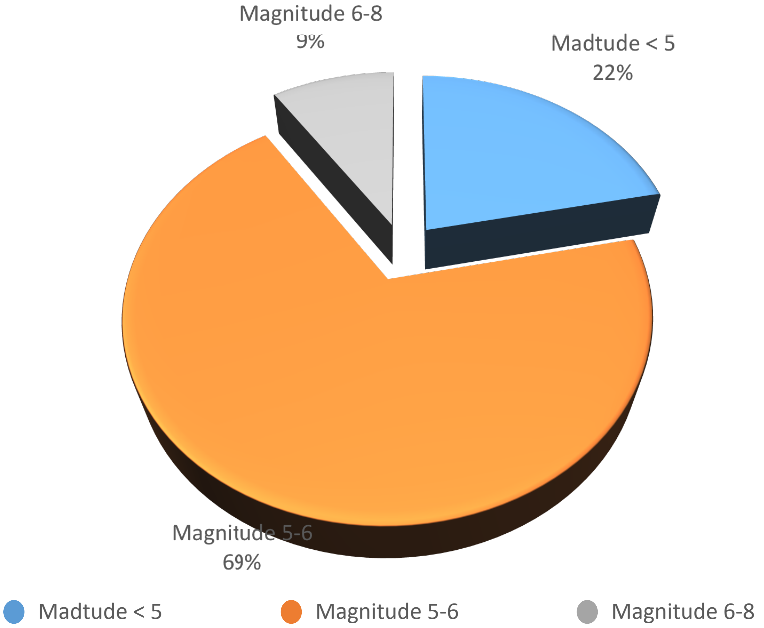


Figure 5. The magnitude of earthquakes that occurred in Indonesia from 12th of June 2018 to 20th of July 2019 which are used for testing the tsunami application 4 minutes after the earthquake.

Figure 5 shows the distribution of magnitude for the earthquakes that are used in the trial. Earthquakes with magnitudes less than 5 are 65 (9%) of the total used earthquakes and for earthquakes with magnitudes of 5 to 6 are 207 (69%). The total earthquakes with magnitude less than 6 are 272 (78%). For the of the tsunami applications previous versions, earthquakes with magnitude less than 6 often occurred false warnings (Madlazim, Prastowo, and Hardy 2015), but for early tsunami mitigation applications 4 minutes after the earthquake, there is no false warning. Whereas for earthquakes with magnitudes 6 to 8 there are 28 (22%). Based on the results of the tsunami early warning application output there is only one earthquake that generate a tsunami, the earthquake that occurred in Palu on 28th September 2018 (Fig. 3).

4. CONCLUSIONS

Tsunami early warning application 4 minutes after the earthquake has been developed and tested in real time at the research and development centre of Meteorology Climatology and Geophysics Council, Jakarta, INDONESIA by using 300 earthquakes that occurred in Indonesia since June 12th, 2018 to July 20th 2019. The results of the tests indicate that tsunami early warning applications 4 minutes after the earthquake meets the eligibility requirements.

Acknowledgment

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