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Preliminary Magnitude of Completeness Quantification of Improved BMKG Catalog (2008-2016) in Indonesian Region

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Abstract. We present a magnitude of completeness (Mc) quantification based on BMKG improved earthquake catalog which generated from Ina-TEWS seismograph network. The Mc quantification can help us determine the lowest magnitude which can be recorded perfectly as a function of space and time. We use the BMKG improved earthquake catalog from 2008 to 2016 which has been converted to moment magnitude (Mw) and declustered. The value of Mc is computed by determining the initial point of deviation patterns in Frequency Magnitude Distribution (FMD) chart following the Gutenberg-Richter equations. In the next step, we calculate the temporal variation of Mc and b-value using maximum likelihood method annually. We found that the Mc value is decreasing and produced a varying b-value. It indicates that the development of seismograph network from 2008 to 2016 can affect the value of Mc although it is not significant. We analyze temporal variation of Mc value, and correlate it with the spatial distribution of seismograph in Indonesia. The spatial distribution of seismograph installation shows that the western part of Indonesia has more dense seismograph compared to the eastern region. However, the eastern part of Indonesia has a high level of seismicity compared to the western region. Based upon the results, additional seismograph installation in the eastern part of Indonesia should be taken into consideration.

1. Introduction

Indonesian earthquake catalog has experienced a major improvement as implications of significant development seismograph network since 2005 and released by BMKG in 2008. The seismograph network known as Ina-TEWS (Indonesian Tsunami Early Warning System) cover seismograph station in Indonesia and produced improved earthquake catalog. The quality of earthquake catalog is a primary issue and need a special attention because it will be a primary input for seismological earthquake and tectonic analysis.

Magnitude of Completeness (M_c) analysis is one of the effective methode to prove the reliability of earthquake catalog. M_c value show the lowest magnitude which can be recorded complete as a function of space and time. The value is represent sensitivity of seismograph network to detect earthquake complete in space and time. Seismograph density in a region can affect the M_c which is the more dense the network, the more small the M_c of the catalog. Incomplete catalog, generally in lower magnitude can not be used because it have ambiguity so can affect seismicity calculation. Therefore, the analysis of M_c

become essential as a preparation step to makesure earthquake data that will allowed in next calculation. Moreover, identification of seismograph network development affect on M_c variation need a crucial attetion to analyze network performance.

This study is focuse to calculate M_c that affected by the development of the seismograph network in certain time. We used earthquake catalog owned by BMKG which records Indonesian seismicity based on latest earthquake catalogs from 2008 - 2016. Previous research to detect M_c in Indonesia show that M_c is 5,0 and identified as part of seismic hazard analysis [1]. But, this research used compiled catalog from several source, so that, the M_c that they got can not represent the indonesia seismograph network performance. In this research, the analysis is done by correlating BMKG magnitude type with Moment Magnitude (M_w) from GFZ. From that correlation, we obtain Magnitude of Completeness (M_c) and *b*–value distribution around the Indonesian Region. It is a preliminary study to acquire one of many parameters in seismic hazard analysis. We assume that we will get a decreasing M_c in temporal variation due to the development of seismograph and produced vary of *b*-value. Moreover, we will identified the performance density distribution of seismograph network in Western and Eastern of Indonesia by seismicity level.

2. Data and Resources

There are 2 kinds of catalog that used in this study: primary catalogs and reference catalogs. Primary catalog prefers to main catalog that proceed, in this case is BMKG catalog. It covered earthquakes from late 2008 to early 2016, in Indonesia region in area between 95° E to 142° E longitudes and 11° S to 8° N latitudes. It contains about 35675 events with various magnitude type (M, m_b, M_{Lv}, M_w, $M_{w(mB)}$ and M_{wp}) that explained in Table 1.

TABLE 1. Magnitude Type Distribution of BMKG Catalogs 2008-2016.

Magnitude	Abbreviation	Range Data	Number of events
Average Magnitude	M	$1.4 \le M \le 6.4$	15342
Short-period body-wave magnitude	m_b	$3.2 \le m_b \le 7.2$	3013
Local (Richter) Magnitude	M_{Lv}	$1.4 \le M_{Lv} \le 6.6$	16581
Moment Magnitude	M_w	$5 \le M_w \le 6.9$	22
Moment Magnitude from P-waves	M_{wp}	$5.5 \le M_{wp} \le 6.6$	4
Proxy M_w based on m_B	$M_{w(mB)}$	$3.7 \le M_{w(mB)} \le 7.9$	713

Reference catalog used are earthquake catalog from Geo Forschungs Zentrum (GFZ) Potsdam, Germany. We chose this catalog because GFZ have more seismograph installed in Indonesia compare to other foreign seismograph contributor in Indonesia. Moreover, Indonesia has adopted similar method with GFZ to proceed earthquake parameter and known as SeisComp3[2]. Catalog derived in same period and region with BMKG Catalog. We also used seismograph installation document from BMKG to see the additional seismograph that have been installed as shown in Figure 1.

3. Magnitude Homogenization and Declustering

Raw BMKG catalog contains various magnitude type and we have to convert it to become one magnitude type which have similar value by correlating various magnitude type to refference magnitude. Magnitude correlation were proceed by matching earthquake event that occurred in certain time and place that record in test catalog and reference catalog. Next, the correlated events were plotted in a graph (Figure-2) and classified for each BMKG magnitude type. Empirical relationship have derived using least square linear regression method. We correlate it to M_w with consideration that it is a more precise magnitude due to it represent to radiated energy from direct measurement[3].

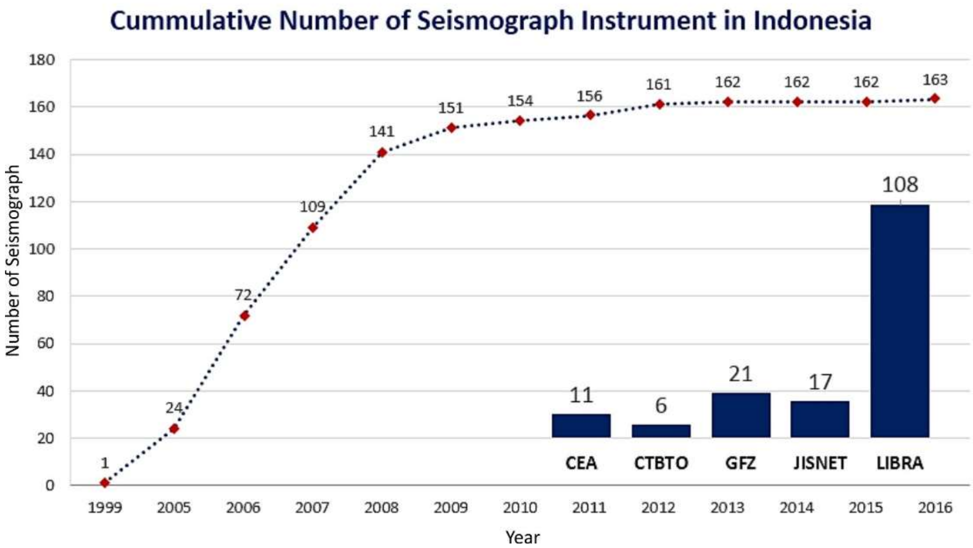

FIGURE 1. Development of seismograph installation in Indonesia from 1999 to 2016. Data source from BMKG. CEA, CTBTO, GFZ, JISNET are foreign seismological institution that contributed seismograph in Indonesia

The acquired empirical relationship above is unique for indonesia region because it converts from specified BMKG catalog. As the result, empirical relationship for each magnitude type are produced that can be seen in Figure-2. Summary of relationship for each magnitude types are listed in Table 2. Those relationship are adopted to get homogen magnitude type in M_w for all earthquake records in BMKG catalog.

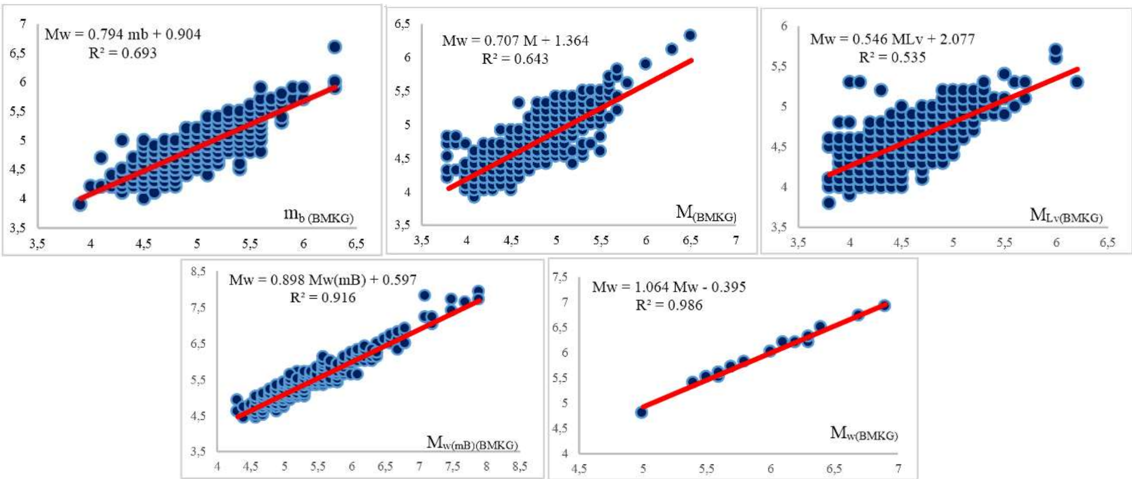

FIGURE 2. Correlating magnitude graph classified into 5 magnitude types (M, m_b, M_{Lv}, M_w and $M_{w(mB)}$. Vertical axis show Mw magnitude from GFZ and horizontal axis show BMKG magnitude. Red line represent linear trend of data distribution

TABLE 2. Correlative Relationship between Moment Magnitude Mw and Various BMKG Magnitude

Empirical Relationship	Number of Events	Determination Coefficient, R^2	Range Data
Mw = 0.707 M + 1.3684	1393	0.6435	$3.8 \leq M \leq 6.5$
Mw = 0.7946 mb + 0.9046	1445	0.6932	$3.9 \leq mb \leq 6.3$
Mw = 0.5468 MLv + 2.076	1144	0.5357	$3.8 \leq Mlv \leq 6.2$
Mw = 1.0646 Mw – 0.3958	16	0.9861	$5.0 \leq Mw \leq 6.9$
Mw = 0.8981 Mw(mB) + 0.5978	476	0.9164	$4.7 \leq Mw(mB) \leq 7.9$

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To remove aftershock, mainshock, and foreshock effect, we applied seismicity declustering to separate from natural earthquake occurrence. Declustering followed conjugate methode from Urhammer (1986) and Gardner-Knopoff (1974) method provide by Openquake. It reduced earthquake event data plotted and remained 25689 that classified as natural earthquakes events of mainshocks.

4. Methodology

Seismicity rate of certain region expressed in Frequency Magnitude Distribution (FMD) with follow Gutenberg-Richter (GR) relationship.

$$\log n(M) = a - bM \tag{1}$$

with $n(M)$ is earthquake quantity with magnitude greater than or equal to M in a certain region with time interval T; a and b value are positive parameters indicating the level and seismicity characteristics[4]. a-value, describe the productivity in given region and time period and b-value that shows the relative size distribution of earthquake.

FMD is expressed in cumulative and increment data plot. The cumulative summing all frequencies above the lowest magnitude. Increment curve counts the number of event with magnitude in each bin with a certain range. GR relationship assume that principally earthquake occurrence have to be distribute linier. It describes that earthquake with higher magnitude should be more infrequently happened than low magnitude earthquake, and earthquake will linearly distributed. But due to limitless seismic network, instrument characteristics, low magnitude earthquake sometime not recorded well, so make the distribution is incomplete.

We analyzed magnitude of completeness (Mc) by estimating point that starts to deviate out of GR trend[5]. It aims to limiting FMD to be conform with conform with GR law. Besides, Mc can determine by maximum curvature method, that select point of maximum curvature in increment curve[6]. Next, FMD below Mc have to be removed to get perfect slope. Data processing of earthquake occurrence distribution was using Openquake Project with based on Python Language. Openquake Project is an open source code for seismic hazard and risk calculation. It provide us to calculating all seismic hazard parameter with the right data input. The b-value is calculated using maximum likelihood method using this following equation.

$$b = \frac{log_{10}^{e}}{M - Mc} \tag{2}$$

With $\boldsymbol{M}$ is the average magnitude and M_c is the Magnitude of completeness.

5. Seismicity Analysis

FMD distribution have to contain the homogenized and mainshock event only [7]. We visualized earthquake catalog in cumulative and increment curve of FMD distribution. FMD proceed in temporal variation start from 2009 to 2016 in Indonesian region. It used to compare and find out variations of Mc and b-value each year, due to difference magnitude distribution density and numbers of earthquake occurred.

Figure 6 expressed that there are different FMD type in each temporal variation that affect to produce different Mc and b-value, due to various earthquake occurrence density. Table 3 showed a summary of difference parameter in each year. It conclude that Mc was decrease with no significance change and parameter seismicity a and b-value is fluctuative. Mc of BMKG Catalog vary from 4.9 and decrease to 4.6. This result compare with development of seismograph installation (Figure 1) in Indonesia had affected Mc of Indonesia, although development were not significance. Temporal seismicity were observed with applied the Mc and b-value each year and showed by Figure 4 and conclude that seismicity level in Western Indonesia higher than Eastern of Indonesia.

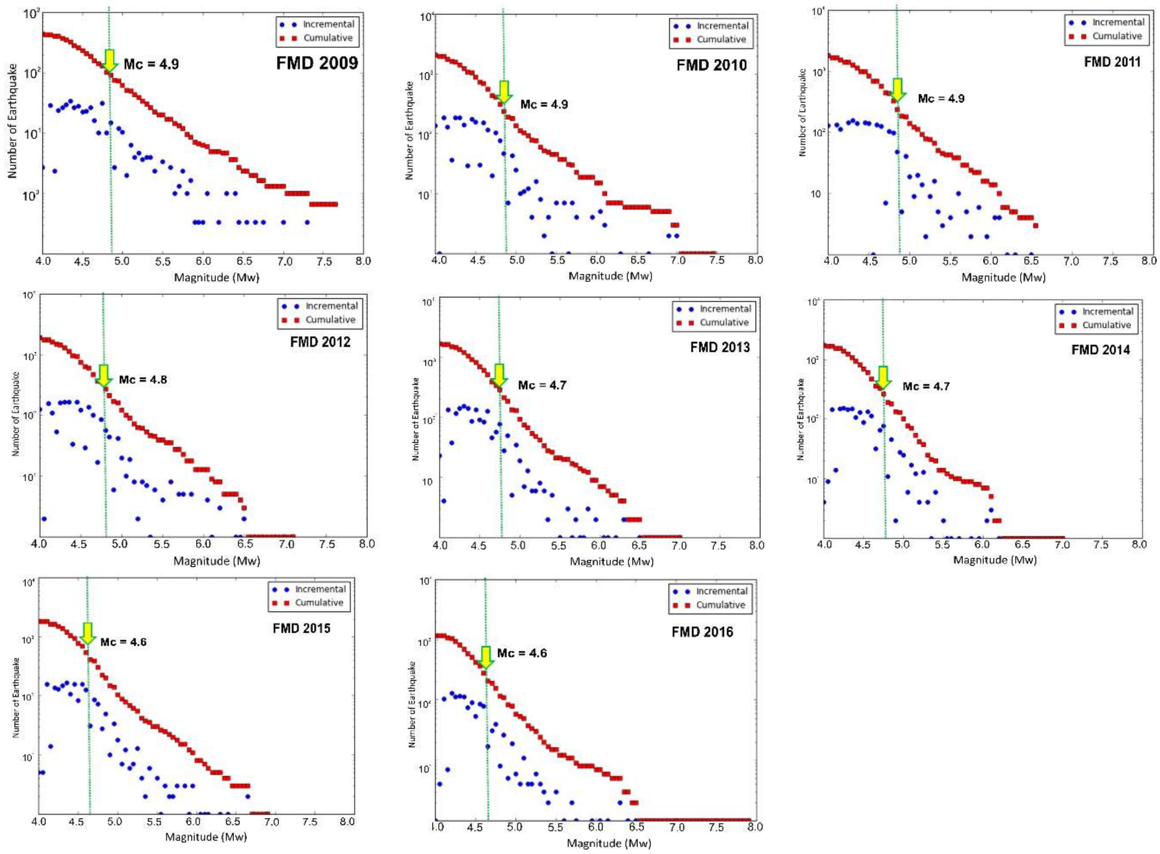

FIGURE 3. Variation of FMD from 2008 to 2016. Different distribution of FMD in each year results in different variation of Mc (marked by black dotted line)

Temporal seismicity were observed with applied Mc and b-value each year and showed by Figure 4. Colour scales shows the normalized earthquake occurence in certain years. As we can see, Eastern region of Indonesia have a higher level of seismicity compare to western region. If we matched this assumption with seismograph distribution in Figure 5, we can see that western part of Indonesia has more dense seismograph compared to the eastern region. However, the eastern part of Indonesia has a high level of seismicity compared to the western region.

TABLE 3. Summarize of analysis seismicity temporal variation

Year	Number of Events	Magnitude Completeness	b-value	a-value
2009	2460	4.9	0.75 ± 0.02	11.82 ± 3.52
2010	3168	4.9	0.76 ± 0.01	0.11 ± 0.00
2011	2336	4.9	0.74 ± 0.03	13.06 ± 4.46
2012	2812	4.8	0.76 ± 0.02	15.84 ± 4.35
2013	2130	4.7	0.79 ± 0.02	24.84 ± 5.30
2014	2415	4.7	0.81 ± 0.02	31.43 ± 6.11
2015	3173	4.6	0.78 ± 0.02	65.50 ± 11.33
2016	1528	4.6	0.79 ± 0.02	136.65 ± 36.54

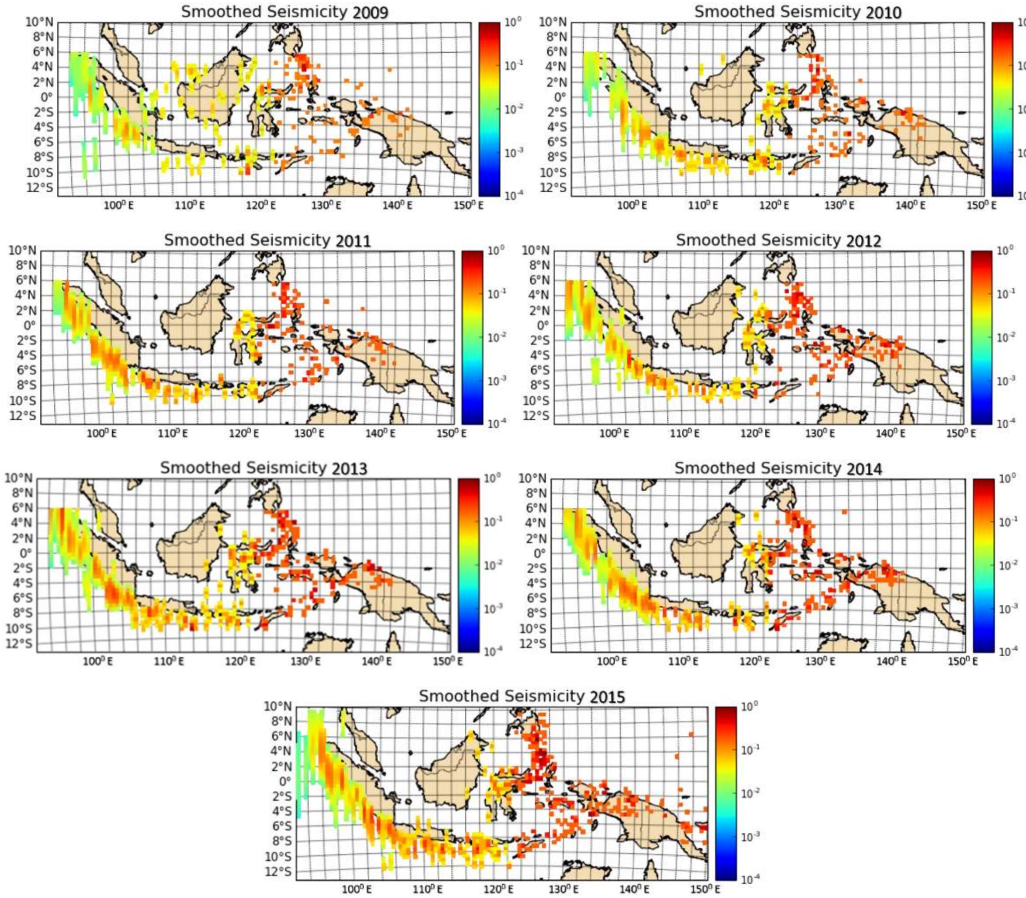

FIGURE 4. The seismicity temporal variation from 2008 to 2015. It has been plot depend on amount of earthquake that happened in certain time period. High seismicity level tendency in east part of Indonesia, and moderate seismicity level distribution disseminated from Sumatra to Java.

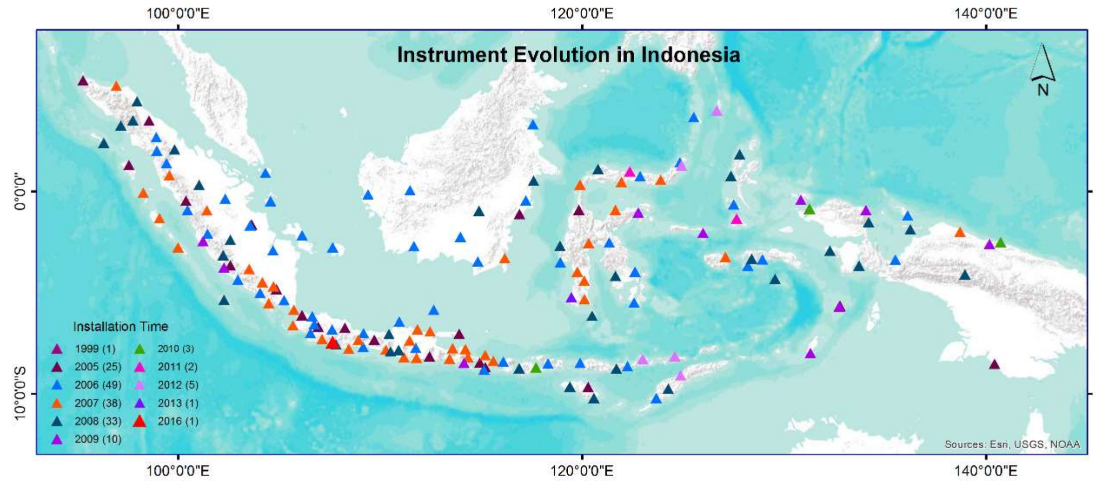

FIGURE 5. Seismograph distribution in Indonesia shows that western region have more dense seismograph installed compare to eastern region of Indonesia. Basemap source derived from ESRI, USGS, and NOAA

6. Summary

Seismicity Analysis for determining b-value parameter as preliminary quantifying have proceed based on latest earthquake catalog in Indonesian region from 2008 to 2016. Some products that produced are empirical relationship between various BMKG magnitude type correlate to Moment Magnitude (Mw) of GFZ-Potsdam and Mc variation of Ina-TEWS seismograph network. Mc are decreasing annually proved that the development of seismograph during 2008-2016 has affect Mc although it is not really significant. Consider to seismograph network distribution, it showed that the western part of Indonesia has more dense seismograph compared to the eastern region. However, the eastern part of Indonesia has a high level of seismicity compared to the western region. Based upon the results, additional seismograph installation in the eastern part of Indonesia should be taken into consideration. Another method will be improved to get more reliable quatification and seismicity parameters.

7. Acknowledgements

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