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

H C Diantari¹, W Suryanto¹, A Anggraini¹, T M Irnaka¹, P Susilanto² and D Ngadmanto²

¹Geophysics Laboratory, Department of Physics, Faculty of Mathematics and Natural Sciences, Gadjah Mada University, Yogyakarta, Indonesia
²Meteorological Climatological and Geophysics Agency (BMKG)

hastin.chandra.d@mail.ugm.ac.id

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 (Mₖ) analysis is one of the effective method to prove the reliability of earthquake catalog. Mₖ 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 Mₖ which is the more dense the network, the more small the Mₖ 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 Mₖ
become essential as a preparation step to make sure earthquake data that will be used in next calculation. Moreover, identification of seismograph network development affects on $M_c$ variation need a crucial attention to analyze network performance.

This study is focused 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 the latest earthquake catalogs from 2008 to 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 sources, 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 ($M, m_b, M_{LV}, M_w, M_{w(mp)}$, 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            | $M$          | $1.4 \leq M \leq 6.4$ | 15342            |
| Short-period body-wave magnitude | $m_b$       | $3.2 \leq m_b \leq 7.2$ | 3013             |
| Local (Richter) Magnitude     | $M_{LV}$     | $1.4 \leq M_{LV} \leq 6.6$ | 16581            |
| Moment Magnitude              | $M_w$        | $5 \leq M_w \leq 6.9$ | 22               |
| Moment Magnitude from P-waves | $M_{wp}$     | $5.5 \leq M_{wp} \leq 6.6$ | 4                |
| Proxy $M_w$ based on $m_b$    | $M_{w(mp)}$  | $3.7 \leq M_{w(mp)} \leq 7.9$ | 713              |

Reference catalog used are earthquake catalog from Geo Forschungs Zentrum (GFZ) Potsdam, Germany. We chose this catalog because GFZ has 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 reference 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].

Reference
The acquired empirical relationship above is unique for Indonesia 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.

### Table 2. Correlative Relationship between Moment Magnitude \( M_w \) and Various BMKG Magnitude

| Empirical Relationship        | Number of Events | Determination Coefficient, \( R^2 \) | Range Data               |
|------------------------------|------------------|--------------------------------------|--------------------------|
| \( M_w = 0.707 M + 1.3684 \) | 1393             | 0.6435                               | \( 3.8 \leq M \leq 6.5 \) |
| \( M_w = 0.7946 m_b + 0.9046 \) | 1445            | 0.6932                               | \( 3.9 \leq m_b \leq 6.3 \) |
| \( M_w = 0.5468 M_{LV} + 2.076 \) | 1144            | 0.5357                               | \( 3.8 \leq M_{LV} \leq 6.2 \) |
| \( M_w = 1.0646 M_w - 0.3958 \) | 16              | 0.9861                               | \( 5.0 \leq M_w \leq 6.9 \) |
| \( M_w = 0.8981 M_w(mB) + 0.5978 \) | 476            | 0.9164                               | \( 4.7 \leq M_w(mB) \leq 7.9 \) |
To remove aftershock, mainshock, and foreshock effect, we applied seismicity declustering to separate from natural earthquake occurrence. Declustering followed conjugate method 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.

\[
\log n(M) = a - bM
\]

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.

\[
b = \frac{\log_{10} e}{M - Mc}
\]

With \(M\) is the average magnitude and \(Mc\) 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 occurrence 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.

| 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 quantification and seismicity parameters.

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