# Determination the Magnitude of Completeness, b-Value and a-Value for Seismicity Analysis in East Java, Indonesia

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# Determination the Magnitude of Completeness, *b*-Value and *a*-Value for Seismicity Analysis in East Java, Indonesia

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**Abstract.** Determine of magnitude of completeness (Mc), *b*-value and *a*-value are essential for a correct interpretation of seismicity analysis earthquake catalogue IRIS of East Java, Indonesia during the period 1990-2020. All estimated parameters were analyzed by apply The Maximum Curvature (MAXC) method. This method is a fast and straightforward way to estimating Mc and consists in determining the point of the maximum curvature by calculating the maximum value of the first derivative of the Frequency-Magnitude distribution (FMD) curve. In practice, this matches the magnitude bin with the highest occurrence frequency of events in the cumulative and non-cumulative of FMD. The value of the magnitude of completeness, which was evaluated on the frequency-magnitude distribution, was found range from Mc 3.4 to 4.0. Then, *b*-value (0.73 to 0.82 ± 0.02) and *a*-value 5.560 to 6.312 was obtained for the area Wongsorejo and the Montong faults in East Java and which is characterized by more heterogeneous crustal structure. The areas that have low *b*-value indicated as the area with a high seismic moment release and high stress accumulation. Low *b*-value areas are located mainly along the Java Trench. Seismicity of East Java is a result of the combined impacts of complex tectonic features. Understanding and clarifying the mechanisms of these tectonic features in relation to Mc, *b*-value and *a*-value can help us to better assess seismic risk in subduction zones.

**Keywords**: Magnitude of completeness; seismicity; East Java.

## 1. Introduction

The Java island, especially in East Java where high seismic activity has long been documented, owing to the confluence of the Indo-Australian plate and the Eurasian plate that moving at very high relative speeds [1,2]. Contemporary oblique subduction in East Java was caused by the down going Indo-Australian plate moves northeastward under the overriding Eurasian plate. The rate of the convergence oblique subduction varies from 63 mm / year in the south of Sumatra and Java, 54 mm / year in the north of Sumatra and Java, and 39 mm / year around the offshore Andaman Island [2,3]. The geodynamic condition of the active deformation around Sunda and Java trench has implications for frequent earthquakes in East Java, especially along the southern coast of East Java [4,5].

Meanwhile, there are three faulting segments that have the potential to cause earthquakes in the East Java, the Kendeng fault, the Montong fault, and the Wongsorejo fault [6]. The area to watch out for is the intersection or intersection between the faults, because basically in this area the earthquake can generate and potentially cause an earthquake disaster. Based on earthquake catalogue from the

Incorporated Research Institutions for Seismology (IRIS) in the East Java with coordinates 6.09° - 9.57° S and 110.92° -114.52° E there are 776 earthquake events were recorded in the last decade by a seismograph network with magnitudes varies between Mw 3 Mw to Mw 10 and the depths varies from 0.1 km to 100 km. More than two large earthquakes have been recorded in the study area: the 1994 Mw 7.9 and the 2006 Mw 7.8 earthquakes (Figure 1). Both earthquakes triggered tsunamis on Java island, with high wave up to 13 m and 8 m respectively, which caused significant damage and more than 600 deaths [7].

Responding to tectonic settings and earthquake history of East Java, it is necessary to do a fundamental study of seismicity based on earthquake history. Seismotectonic characteristics and intra plate tectonic activity of study area can indicate based on seismicity. Seismicity is a measure to compare seismic activity between one region and another. Seismicity parameters are numerical constant that can be used as a measure of seismicity of an area. Seismicity parameters consist of seismic activity (*a-value*), rock fragility level (*b-value*), and magnitude of completeness (Mc).

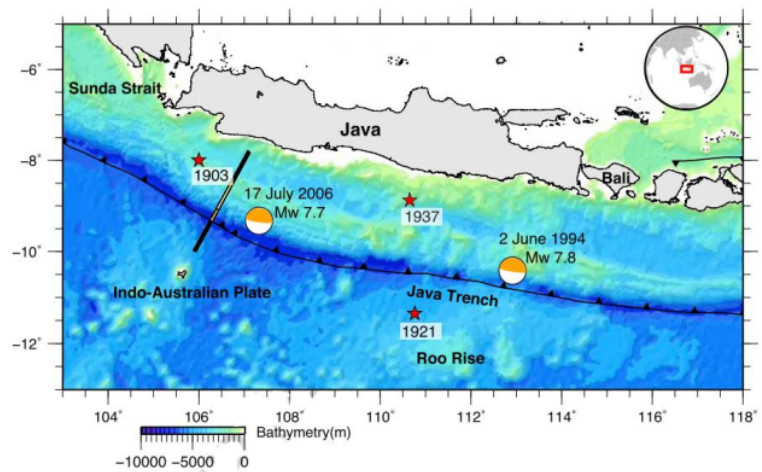


**Figure 1.** Two Large Earthquakes Have Been Recorded in East Java: the 1994 Mw 7.9 and the 2006 Mw 7.8

Seismicity in the East Java has been studied with Shohaya [5]. However, only determine *a*-value and *b*-value are the focus of research, while Mc value and their statistical analysis have not really noticed. The research also concluded that East Java has a low level of rock heterogeneity based on variations in the *b*-value and *a*-value as the main precursors. The recent digital seismic observation periods provide updates that improve the accuracy of earthquake locations. Meanwhile, analysis of small earthquakes such as those occurring in the study area requires an evaluation of the Mc value which is the minimum parameter for an earthquake event that cannot be ignored during the recording process by the seismograph network.

The value of Mc not only shows the ability of a seismogram to record event of earthquakes, but also is an important parameter in estimating the level of seismicity and the *b-value* of the Gutenberg-Richter power law distribution [8,9]. Mc value is defined as the ability of seismograph network to detect the lowest magnitude at which 100% of the earthquakes in a space-time volume. With the availability of seismic data in East Java, the spatial distribution of Mc value, *b*-values, and *a*-values were investigated. The motivation of this research is to achieve *b*-value, *a*-value and Mc in the earthquake catalogue of East Java.

## 2. Data Processing

We used seismicity data from the IRIS catalogue with coordinates 6,09°-9,57° S and 110,92°-114,52° E, which provides revised information on earthquakes that took place up to 2020. We selected the events that were recorded in the study site since 1990, with a focal depth shallower than 300 km. For over 776 earthquakes that occurred during 2010-2020. There are many earthquake events which do not have complete attributes for example no magnitude assigned; so they cannot be treated for the final catalogue and must be filtered. If we used this catalogue to study, the first step is to secure magnitude scale homogeneity by converting to moment magnitude Mw. After converting to the moment magnitude, we identification of main shocks to the foreshocks and aftershocks, the process commonly known as declustering process. The main shocks is separated from the foreshocks and aftershocks based on the algorithm developed by Reasenberg [10,12]. This algorithm basically eliminates the earthquakes that are in the vicinity of a large earthquake within a fixed range of distances and times.

## 3. Method

To understanding the characteristics of an earthquake catalogue of East Java the first step toward we have to do is discovering the starting time of the best-quality catalogue. Determine seismicity parameters (the Mc-value, *a*-value and *b*-value) are part of understanding the characteristics of an earthquake catalogue. Mostly methods to determine the seismicity parameters of earthquake catalogue is based on Gutenberg-Richter power-law distribution of earthquakes. In this study, we used Maximum Curvature-method (MAXC) [10,13,14]. The code of MAXC is freely available included with the seismicity analysis software package called ZMAP [10], which is written in Matlab commercial software language.

MAXC is the method that developed by Wiemer and Wyss (2000). The first step to determine the magnitude of completeness is to define the point of the MAXC by computing the maximum value of the first derivative of the frequency-magnitude distribution (FMD) curve [10,13,14].

The relationship between the frequency of occurrence and the magnitude of earthquakes described by the frequency-magnitude distribution [9,15,16]:

$$log_{10} N(M) = a - bM \quad (1)$$

Where *N*(*M*) is the frequency of earthquakes with magnitudes larger or equal than M, in this study M is Mw ≥ 6.0 . The *a* and *b* are constant. The constant *a* called *a*-value that described as seismic activity and the constant *b* called *b*-value. The *b*-value represents the slope of the cumulative number relative to the magnitudes. According to the equation (1) *a*-value and *b*-value estimator is as follows:

$$b = \frac{log_{10}(e)}{\left[\langle M\rangle - \left(M_c - \frac{\Delta M}{2}\right)\right]} \quad (2)$$

$$a = \log N(M \geq 6{,}0) + \log (b \ln 10) + (6{,}0b) \quad (3)$$

Here $\langle M \rangle$ is the mean magnitude of the sample, $\Delta M$ is the binning width of the catalogue, Mc is the lower limit of the earthquake magnitude in the study area and Log e: 0.4343 [9,15,16].

The *a*-value is dependent on observation period and seismicity of the area. The *a*-value for the cumulative frequency for Mw ≥ 6.0. N is the frequency of the earthquake occurring at a certain magnitude. The value of *a*-value always changes and depends on the length of the observation period and the average size of the earthquake area being reviewed.

## 4. Results and Discussion

The following figure shows how the constant of variation of *a*-value, *b*-value, and Mc of earthquakes as a function of time and number of all earthquakes that occurred in East Java which located between 110°-115° E and 5°-10° S in the last three decades (Figure 3, Figure 4, and Figure 5). All three images involve all earthquakes either large earthquakes (more than Mw 6.0) or small and medium earthquakes

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(range from Mw 1.0 to Mw 5.0) which occurred in the study area, over the past three decade period. The completeness of earthquake data available from Mw 4 to Mw 8.5 was related to the development of seismograph technology development.

Fluctuation in the number of earthquakes during years as shown in Figure 2 shows how unpredictable earthquakes, and looking from year to year can be determined analysis of the trend of earthquake events. It can be seen that there is a tendency for earthquakes to increase from year to year (Figure 2). Even after the earthquake in 2014 the tendency for earthquakes to occur was even sharper. This is thought to be caused by the process of achieving a stress balance experienced by the plates, resulting in continuous aftershocks until an energy balance occurs.

These are pictures of all earthquakes occurred in East Java region in the last 30 years and the variations in earthquake magnitude as a function of time and number (Figure 2). The three figures involve all earthquakes, including large (from Mw 7.0 to Mw 8.5) and small and medium (from Mw 4.0 to Mw 6.9) which occurred in the study area during a period of 30 years. The availability of earthquake data ranging from magnitude Mw 4 to Mw 8.5 is highly affected by the development of seismograph technology. Therefore, in the last 30 year even small earthquakes magnitudes could be recorded by seismographs as the improvements in information and communication technology as well as the number of seismograph stations around the world. This increase has helped seismological center to detect small earthquakes in the previous decades. Large earthquakes occur less frequently than small earthquakes, which occur more regularly. Large earthquakes are judged to have a greater impact on geographic range and damage, and are more likely to be accurately recorded over long periods of time [11].

The occurrence of earthquakes in the past cannot necessarily be considered as a clear indication of future earthquake trends (unfortunately many scientists believe it because they just simply perceive on the existing trends, without considering other factors, such as the *b*-value and others). Thus, we have to be careful in interpreting past events. However, it is obvious that we currently live in a time when the frequency of earthquakes is increasing. This will be interesting to see if in the near future there will be earthquakes with an increasing trend as it is today.

The estimation of Mc as time function shows how the magnitude and number of earthquakes that occur in a function of time are related, which aims to see the evolution of the Mc value every 10 years from 1990 to 2020. This can be seen in Table 1. The average, Mc value has shrunk over the past three decades. This shows an increase in the quality of earthquake data recording and processing which is affected by the increase in the number of stations, the sensitivity of the tools and methods used.

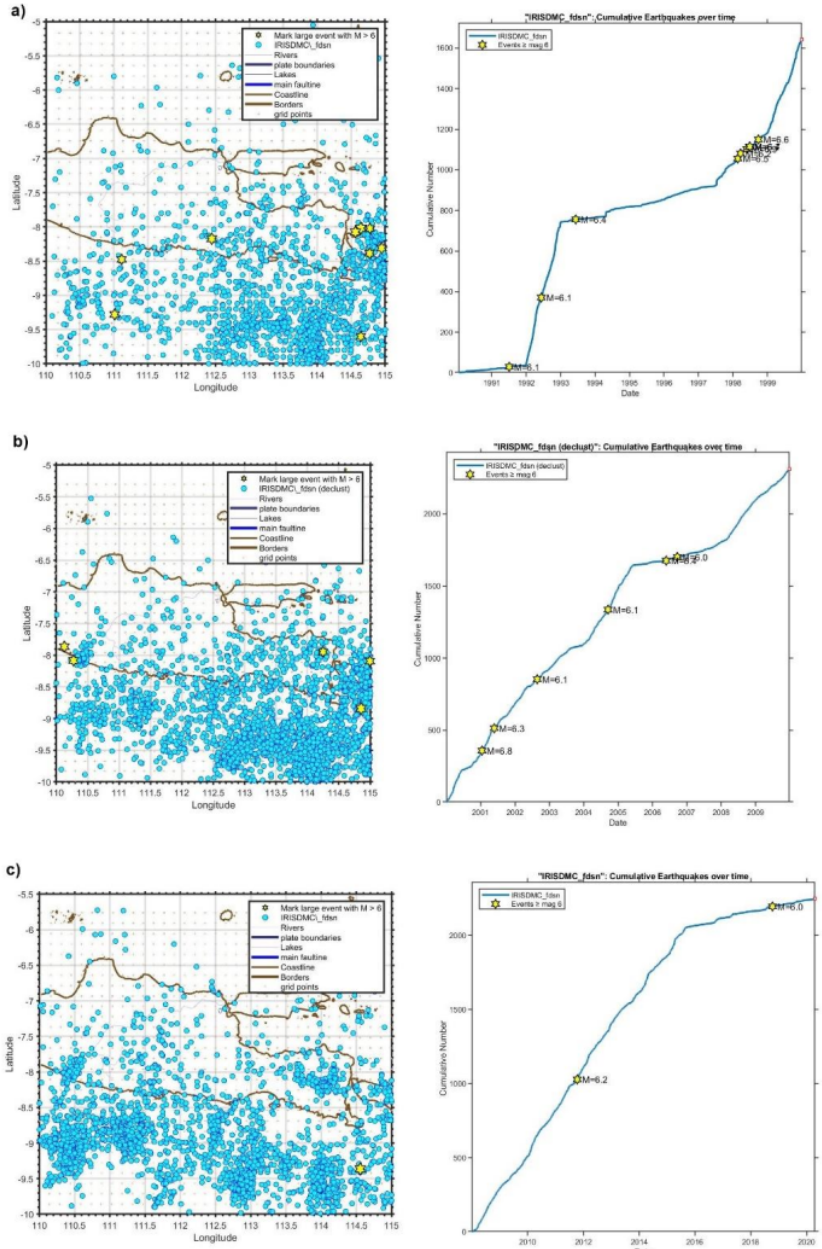


**Figure 2.** 1685 Events (Marked with Blue Circle) and the Large Events (Marked with Yellow Stars) That Used in This Study Based On The IRIS Earthquake Catalogue and Cumulative Earthquake Overtime Selected Events in 1990-2020, (a) from 1990 to 2000; (b) from 2000 to 2010; and (c) from 2010 to 2020

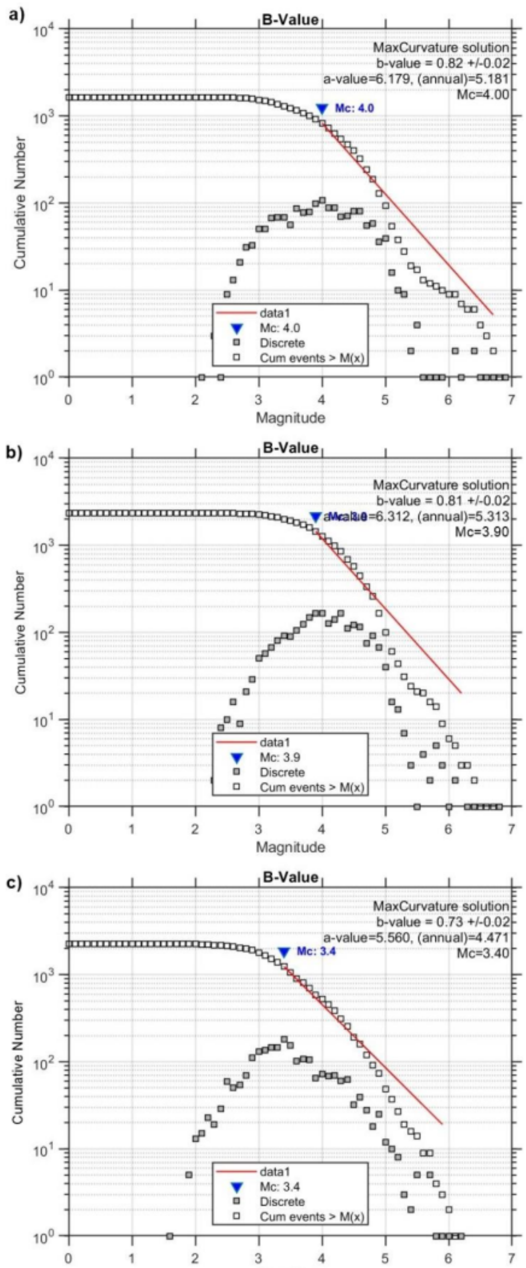


**Figure 3**. Frequency-Magnitude Distribution for Cumulative Number of Earthquakes from 1990 to 2020. The Best Fit and Magnitude of Completeness are Given on the Red Solid Line and the Blue Triangle. This Graphs Using MAXC Method in East Java Based on IRIS Earthquake Catalogue in Three Decades (a) from 1990 to 2000; (b) from 2000 to 2010; and (c) from 2010 to 2020 Results are Listed in Table 1

**Table 1.** Mc, *a*-values, and *b*-values Determined for the Data Used in Figure 3

| Period | Mc | *a*-value | *b*-value |
|---|---|---|---|
| **1990-2000** | 4.00 | 6.179 | $0.82 \pm 0.02$ |
| **2000-2010** | 3.90 | 6.312 | $0.81 \pm 0.02$ |
| **2010-2020** | 3.40 | 5.560 | $0.73 \pm 0.02$ |

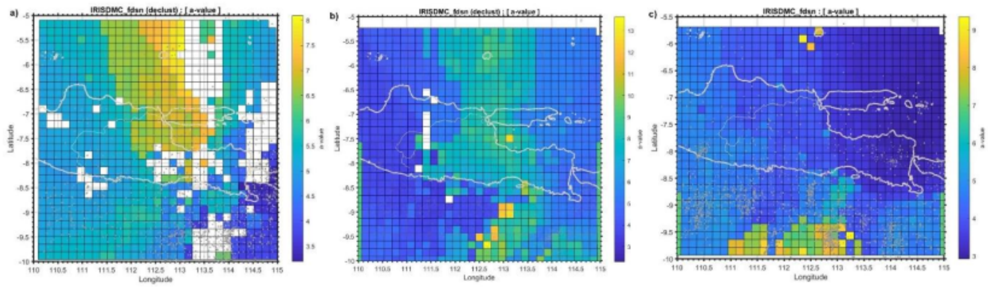

**Figure 4**. Variation in the *a*-Value Constant of Seismicity in East Java Based on the IRIS Earthquake Catalogue in Three Decades (a) from 1990 to 2000; (b) from 2000 to 2010; and (c) from 2010 to 2020

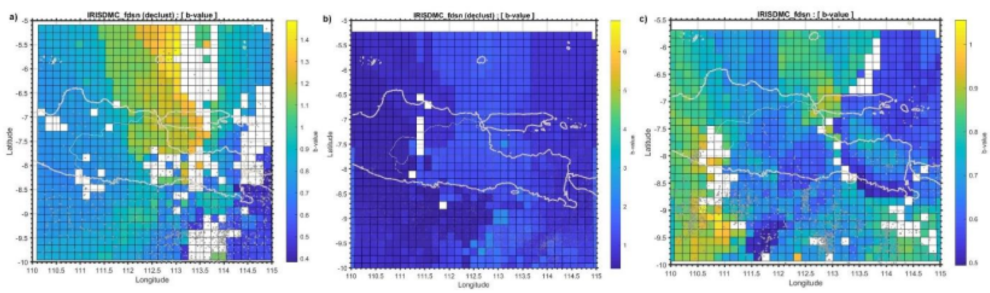

**Figure 5**. Variation in the *b*-value Constant of Seismicity in East Java Based on the IRIS Earthquake Catalogue in Three Decades (a) From 1990 To 2000; (b) From 2000 To 2010; and (c) From 2010 To 2020

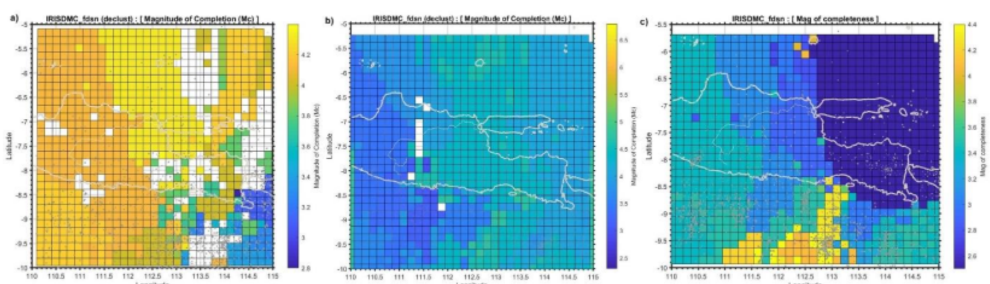

**Figure 6**. Variation in the Magnitude of Completeness (Mc) in East Java Based on IRIS Earthquake Catalogue in Three Decades (a) From 1990 To 2000; (b) From 2000 To 2010; and (c) From 2010 To 2020

The results of the mapping of Mc values for the East Java region for the IRIS catalogue using the MAXC method with bin size can be seen in Figures 6 (a), 6 (b), and 6 (c). From Figures 6 (a) and 6 (b) it can be seen that the northern parts of East Java have relatively low Mc values, namely around Mw

4.6 – Mw 5.0. Variations in Mc values can also be analyzed based on the position of the earthquake recording station used by the IRIS catalogue.

Another factor that causes variations in the value of Mc is related to the availability of real time data from local earthquake recording stations. For the eastern part East Java, the value of Mc is quite high because there is only one station that covers earthquake recording which is located off the coast of southern East Java. The earthquake data are not recorded properly due to this reason. After mapping the Mc value, the *b*-value is also mapped, the results can be seen in Figures 5 (a), 5 (b), and 5 (c).

Based on the MAXC method, the *b*-value is obtained from 0.73 to 0.82. From the research results of previous researchers, a low *b*-value usually correlates with a high seismic activity level, while a high *b*-value means the opposite. In this study, it is seen that the variation of the *b*-value is low in the southern part of East Java and the southern part of East Java, which means that the potential for large earthquakes is quite high in this region. The relatively low *b*-value indicates that the subsurface rock stress level of East Java is very high so that triggering for large earthquakes likely to occur.

The results of variation of *a*-value can be seen in Figures 4 (a), 4 (b), and 4 (c) which similar to the distribution of the b-values. Low *a*-values can also be seen for the southern and eastern parts of East Java. A low *a*-value indicates a low seismic frequency level but the potential for a large earthquake to occur is quite high. If the area has a high *a*-value, then the area has a high seismic frequency but the earthquake magnitude that occurs in that area is relatively low.

## 5. Conclusion

Based on the research that has been done, the following conclusions can be drawn: the estimated average Mc value for East Java with coordinates of 6.09°-9.57° S and 110.92°-114.52° E from January 2010 to April 2020 taken from the spatial IRIS earthquake catalogue using the MAXC method. The Mc value, which was evaluated on the FMD curve, was found to range from Mc 3.4 to 4.0. Then, *b*-value (0.73 to 0.82 ± 0.02) and *a*-value 5.560 to 6.312. From the results of mapping, areas with the lower Mc were the western part of East Java and the northern part of East Java (Java Sea). The average *b*-value of 0.73 indicated that East Java is an area with a moderate to large earthquake potential. The average *a*-value of 5.560 indicates that this region has a relatively high level of seismicity.

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