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A STUDY OF EARTHQUAKE POTENTIAL ANALYSIS IN CENTRAL JAVA AND YOGYAKARTA PROVINCES, INDONESIA BASED ON THE CALCULATION OF A AND B-VALUES WITH THE MAXIMUM LIKELIHOOD METHOD

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ABSTRACT

There are several active faults in Central Java and Yogyakarta (Indonesia), such as the Opak Fault, Baribis-Kendeng Fault, Merapi-Merbabu Fault, and others. In addition, Central Java and Yogyakarta are located near the subduction zone in the south of Java Island due to the collision of the Eurasian Plate and the Indo-Australian Plate. This has contributed to the fact that earthquakes can occur in Central Java and Yogyakarta. The purpose of this research is analyze the earthquake potential in Central Java, which includes an analysis of the a-value (seismicity level) and b-value (regional stress level) as an earthquake hazard mitigation effort. The Gutenberg-Richter equation expresses the relationship between earthquake frequency and magnitude as a straight-line equation containing the a-value and b-value parameters. The calculation of the b-value of the Gutenberg-Richter equation can be conducted with a modification of the maximum likelihood method. From 122 main earthquake events in the IRIS catalog, the values for depth (0-33) km are b = 1.01 ± 0.01 and a = 6.31, for depth (0-10) km, b = 1.44 ± 0.2 and a = 7.58; while for depth (10-33) km, b = 0.91 ± 0.1 and a = 5.73. The depth of (0-33) km and the depth of (0-10) km shows high a-value and b-value, while the depth of (10-33) km shows low a-value and b-value.

Keywords: earthquake hazard, faults, maximum likelihood, a-value, b-value.

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INTRODUCTION

Central Java and Yogyakarta provinces are located close to the Java subduction zone caused by the Indo-Australian Plate subducting into the Eurasian Plate. Several active faults are also found in Central Java and Yogyakarta Special Region (DIY), such as the Opak Fault, Pati Fault, Baribis-Kendeng Fault, Merapi-Merbabu Fault, Ungaran Fault, and so on(PuSGeN, 2022) as presented on Figure-1. It seems logically that the potential for earthquake events in the region is quite large. An analysis of earthquake potential in Central Java and Yogyakarta Special Region (DIY) needs to be conducted, in order to map areas that have more potential for earthquakes with a larger scale. The information is expected to be useful as an earthquake disaster mitigation effort, so as to minimize the occurrence of both life and material losses.

The analysis of earthquake potential in Central Java and the Special Region of Yogyakarta (DIY) can be done by calculating the a-value which shows the seismicity level of a region and the b-value which shows the stress level of a region. The calculation is related to the relationship between earthquake frequency and magnitude in the Gutenberg-Richter (1944) equation defined by the following equation:

$$\log N = a - bM$$

where N is the frequency of earthquakes occurring on a magnitude scale greater than or equal to M in a given period of time. The Gutenberg-Richter law equation is a linear equation, with the intersection point to its vertical axis being the a-value parameter, while the gradient of the linear statistical distribution between earthquake frequency-magnitude is called the b-value parameter (Gutenberg and Richter, 1944).

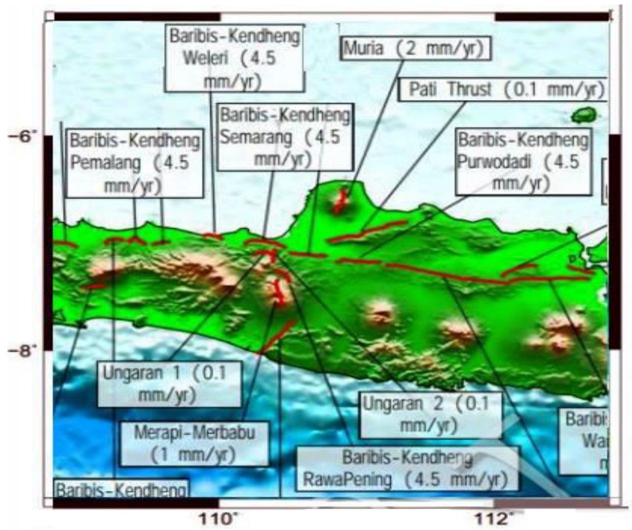

Figure-1. Distribution of active faults on Java Island (Indonesian National Earthquake Map, 2017).

In the b-value calculation, some methods can be used, such as the modified maximum likelihood method to

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estimate the value of the Gutenberg-Richter b-value parameter. Estimating the b-value parameter is done by maximizing the probability function that contains the b-value and magnitude parameters (Aki, 1965, Utsu, 1966). The maximum likelihood method is also known to have a high level of accuracy (Kárník, 2012). The calculation of the b-value with the maximum likelihood method can be formulated as follows:

$$b = \frac{1}{\ln(10)\left[\bar{M} - \left(M_c - \frac{\Delta M}{2}\right)\right]}$$

where $\bar{M}$is the average magnitude with a scale of $M \geq M_c$. The magnitude $M_c$can be interpreted as the magnitude of completeness, which is the smallest magnitude that can be detected properly by the measuring instrument, and ΔM=0.1 which is the binning interval on the magnitude scale [9].

METHODOLOGY

The data that is used in this study is the data sourced from IRIS with a total of 137 events. The maximum depth of the data is 33 km below the earth's surface, because in this study the focus is on earthquakes that occur due to faults. From the data, a-value and b-value were calculated with the help of MATLAB 2007 and Z-MAP 6.0 software (Wiemer and Wyss, 2000).

In the calculation of a-value and b-value, only the main earthquake event is used. Therefore, it is necessary to perform earthquake declustering or clustering, so as to eliminate the effects of preliminary earthquakes and aftershocks. The declustering process uses the Reasenberg method. From 137 earthquake events, 122 main earthquake events were obtained.

Reasenberg (1985) published a method used for declustering. Reasenberg's method makes it possible to link aftershock triggers within earthquake clusters. If earthquake event A is followed by earthquake event B and followed again by earthquake event C, then both A, B, and C are considered to be in the same cluster. When defining the cluster, only the largest earthquake is eventually stored as the main earthquake. In addition, a development in this method is that the space-time distance is based on Omori's Law (for time dependence), as the time from the mainshock increases, the time to wait for the next aftershock also increases proportionally [8].

After the declustering process, a-value and b-value calculations were carried out with 3 depth variations. The depth variations include depth 1 (0-33) km below sea level, depth 2 (0-10) km below sea level, and depth 3 (10-33) km below sea level.

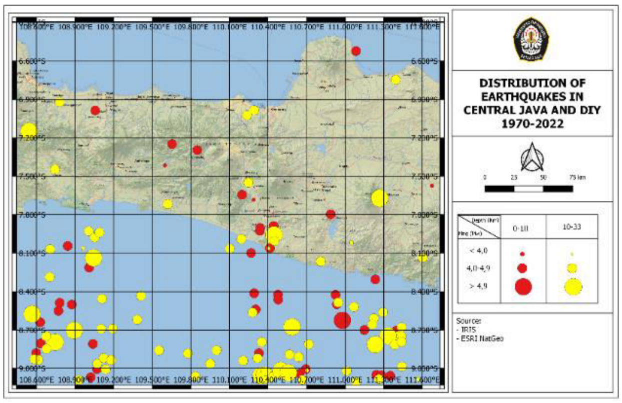

Figure-2. The map of earthquake distribution of Central Java and Yogyakarta before declustering process.

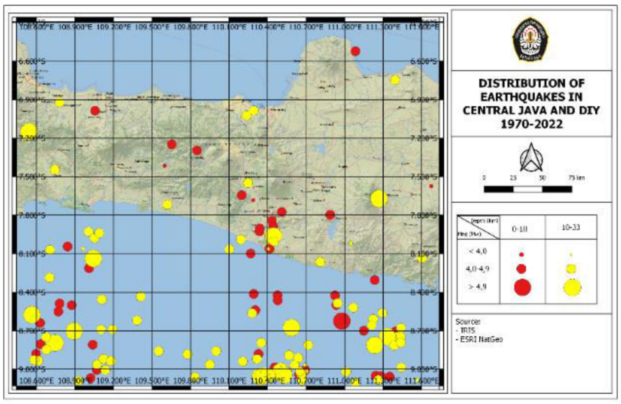

Figure-3. The map of earthquake distribution of Central Java and Yogyakarta after declustering process.

RESULTS AND DISCUSSIONS

Calculation of a-value and b-value with depth variation results in values of b=1.01±0.1 and a=6.31 for depths of (0-33) km shown in Figure 4. At a depth of (0-10) km, the values of b = 1.44 ± 0.2 and a = 7.58 are shown in Figure-5. At a depth of (10-33) km, the values of b=0.91±0.1 and a=5.73 are shown in Figure-6.

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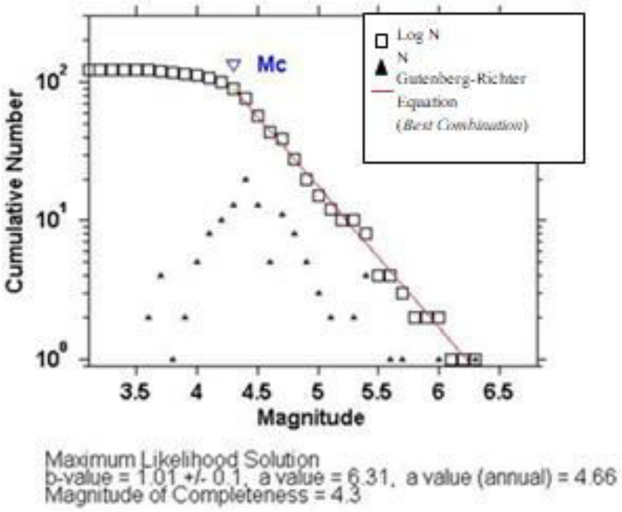

Figure-4. The distribution of the sum of earthquake cumulative frequency and magnitude with the maximum likelihood solution at a depth of (0-33) km.

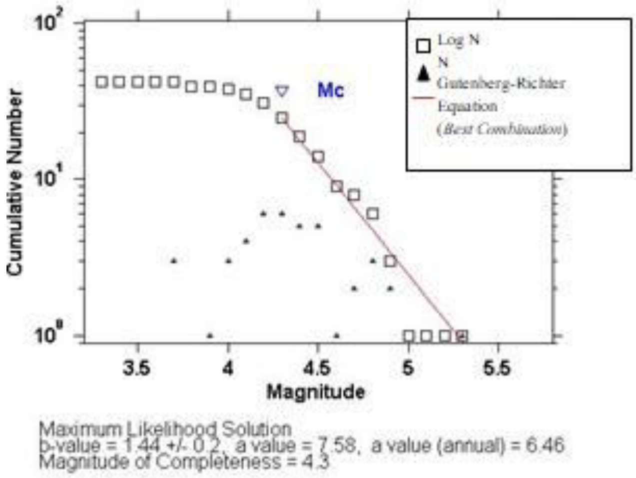

Figure-5. The distribution of the sum of earthquake cumulative frequency and magnitude with the maximum likelihood solution at a depth of (0-10) km.

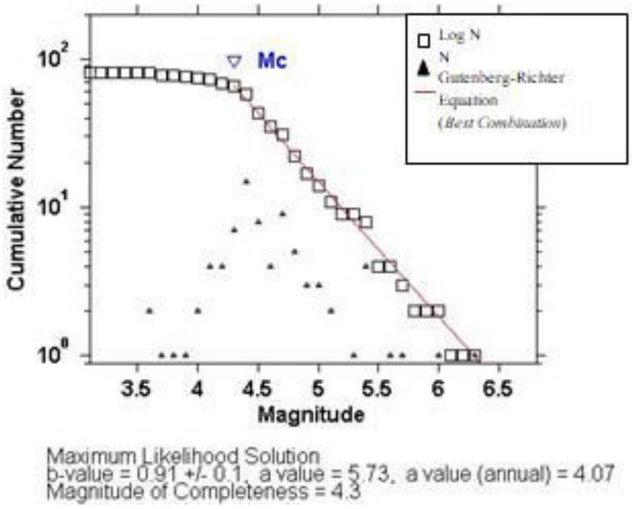

Figure-6. The distribution of the sum of earthquake cumulative frequency and magnitude with the maximum likelihood solution at a depth of (10-33) km.

A b-value of >1 indicates that the accumulation of stress in the area is low, while a b-value of <1 indicates that the accumulation of stress in the area is high [5]. The results show that the b-value for depths of (10-33) km has a low value indicating a high accumulation of stress at that depth, while for depths of (0-10) km and depths of (0-33) km it produces a high b-value indicating a low accumulation of stress in the area.

The a-value at depths of (10-33) km is low because the value is <6, while at depths of (0-33) km and depths of (0-10) km the a-value is high (≥6) (Ernandi, 2020). The value of the a-value correlates with the b-value. A high b-value correlates with a high a-value and conversely a low b-value correlates with a low a-value. The correlation between the a-value and b-value shows that the more fragile the rocks in an area, the higher the seismic activity or the level of earthquake activity will be because stress is rarely accumulated, but more often released, while the harder the rocks in an area, the accumulation of stress is high, and the seismic activity or the level of earthquake activity will be lower.

If the a-value and b-value are linked to the earthquake distribution maps shown in Figures 4, 5 and 6, it can be seen that for depths of (10-30) km, earthquakes with a magnitude ≥5 more frequent than areas with depths of (0-10) km because at these depths the accumulated stress is greater than at depths of (0-10) km.

CONCLUSIONS

As a potential earthquake analysis in the Central Java and Yogyakarta area, after declustering, the a-value is determined to show the level of seismicity and b-value to analyze the level of stress in the study area. Based on the analysis of the modified maximum likelihood method, at a depth of (0-33) km, b = 1.01 ± 0.01 and a = 6.31, for a depth of (0-10) km, b = 1.44 ± 0.2 and a = 7.58; while for a depth of (10-33) km, b = 0.91 ± 0.1 and a = 5.73.

Among the three depth variations, at a depth of (10-33) km, the a-value and b-value are low, which is related to the high level of stress accumulation.

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