Analysis of seismicity level and return period of Bengkulu area earthquake from 1960-2017

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Abstract. In this research, seismicity and the return period of earthquake in Bengkulu and surrounding areas has been analyzed using the relationship between the frequency and the magnitude of earthquakes. Study area is at coordinate points of 1,1-6,4° SL and 99,5°-104,9° EL, whereas the earthquake data used is limited only to 5.0 SR magnitude and 100 km depth from 1960-2017 sourced catalog data from United States Geological Survey (USGS) and using the Zmap Matlab 2007Rb software program. The analysis results that spatial variation b-value is 0.6–2, a-value is 5-15 while magnitude of Completeness is 5,1. And return period of earthquake with magnitude 5 ranges from 0.2-0.5 years, magnitude 5.5 ranges from 1.5-3.5 years, magnitude 6 ranges from 6-12 years, magnitude 6.5 ranges from 15-25 years and magnitude 7 ranges from 10-20 years, magnitude 7.5 ranges from 30-50 years, and magnitude 8 and 8.5 ranges from 100-150 years. Hence the results show that Bengkulu area is an area with high stress level and relatives high magnitude level.

1. Introduction
Earthquakes are rumblings, shaking or rolling of the earth’s surface. It usually happens when two blocks of the earth suddenly slip past one another, or break apart from each other as a result of tension caused by prolonged energy build up.

Bengkulu Province is one of the earthquake-prone areas because it is located at the confluence of the Indo-Australian Plate and Eurasian Plate, which is an active subduction zone in addition to the existence of the Sumatran Fault (Semangko Fault) which slopes several areas in Bengkulu Province and implements active volcanoes in the province Bengkulu (Bukit Kaba) and the volcanic earthquake disaster as a form of tectonic plate subduction activity is the main trigger of the earthquake in Bengkulu Province.

An earthquake measuring 8.03 MW on 4 June 2000 was the beginning of a series of seismic activities in Bengkulu. The earthquake has caused changes in the sea floor that can trigger a tsunami, after that it was followed again. On September 12, 2007 was a shock with magnitude 8.7 SR. The impact and damage caused by this earthquake was greater than the earthquake that occurred 7 years ago. Both of these earthquakes caused quite massive damage in various central cities in Bengkulu Province [1]. Then the next 7 years have resumed precisely on 13 August 2017 an earthquake with magnitude 6.6 SR with a depth of 10 km Location 3,750 LS and 101,560 BT in the Bengkulu area and its surroundings. The earthquake centered on the sea 71 km southwest of North Bengkulu.
Earthquake activity that occurred in Bengkulu Province, such as Bengkulu city, Muko-muko, North Bengkulu (Agramakmur), Kepahiang and Curup, Tais, South Bengkulu (Manna) and Bintuhan is often small and large earthquakes. Return period of earthquakes that are small and large in a certain period of time that often occurs in the area of Bengkulu Province become very important issue to be examined more deeply. Therefore it is necessary to analyze seismicity level and the return period of earthquakes in Bengkulu and surrounding areas in a period of approximately 57 years from 1960 to 2017 using Likelihood Method with the help of Zmap6.0 software 2007Rb.

2. Seismicity and Return Period of Earthquake

Seismicity index states the total number of earthquake events that occur within one year with magnitude greater than the smallest magnitude ($M_0$) in an area. The value of seismicity index is as follows:

$$\log N_1(M \geq M_0) = a_1 - bM_0; \quad N_1(M \geq M_0) = 10^{a_1 - bM_0}$$  \hspace{1cm} (1)

$$a_1 = a' - \log \Delta t$$  \hspace{1cm} (2)

$$a' = a - \log (b \cdot \ln 10)$$  \hspace{1cm} (3)

$$N_n(M_n \geq M_0) = 10(a - \log (b \cdot \ln 10) - \log \Delta t) - bM_0(a_1 - bM_0)$$  \hspace{1cm} (4)

$N_n(M_n \geq M_0)$ is seismicity index for magnitude $M_n \geq M_0$, $a$ and $b$ are constants of the relation frequency-magnitude, $M$ is the magnitude of the earthquake, and $\Delta t$ is the time interval of observation. $a$-value is defined as a level of seismic activity in an area. The high $a$-value in an area means the level of seismic activity in the area is increasingly active. Conversely, if the $a$- value of an area is small, seismic activity is also small [2]. $b$-value is one of parameter of a tectonic condition which depends on the nature of local rock and the level of rock fragility. $b$-value also correlates with stress levels in rocks [3]. The greater of $b$-value means the greater the level of rock fragility and vice versa. In other words, for large $b$-value, the resistance of rocks against the stress should be small. While for small $b$-value, the resistance of rocks to stress should be high.

The return period of earthquake means that earthquakes of a certain scale would be repeated in the same area at a certain time. Average return period of an earthquake can be calculated by the following equation;

$$\theta(M \geq M_n) = \frac{1}{N_n(M_n \geq M_0)}$$  \hspace{1cm} (5)

With $\theta(M \geq M_0)$ is the return period of an earthquake for magnitude $M_n \geq M_0$. $N_n(M_n \geq M_0)$ is a seismicity index for magnitude $M_n \geq M_0$, and $M_0$ is the smallest earthquake magnitude.

3. Data and Methodology

This paper analyze seismicity level and the return period of earthquake occurred in the period 1960-2017 in the Bengkulu and surrounding areas by using likelihood method. Earthquake parameters used are: events of earthquake, epicenter location (latitude and longitude), depth, and earthquake magnitude. This data was obtained from the seismology data portal (USGS) United States Geological Survey for period 1960-2017 with magnitude 5 and depth 0-100 km. The research area is at 1.1°- 6.3° SL and 99.5°-104.9° EL. Steps of data processing are as follows:

a. Determine the research area which is limited by latitude and longitude geographically.

b. Download earthquake data according to location and time period from USGS data.

c. Classification of data is according to ASCII format, namely longitude, latitude, year, month, day, magnitude, depth, hour and minute.

d. Convert all earthquake magnitudes to be moment magnitude (MW), this is caused by the magnitude of the moment is not saturated. The total earthquake data obtained from the USGS.
e. Total amount of earthquake from USGS catalog is 99 but after clustering process the number obtained is 796 earthquake data. The reduction of earthquake data is due to the decomposition process eliminating the effect of foreshock and aftershock. The decluster criteria used in this paper is criteria of Reasenberg.

f. Determine the magnitude value of completeness (MC). Its function is to eliminate earthquake magnitude that not fulfill correlation of cumulative earthquake occurrence relationship with magnitude. The magnitude value of completeness greatly influence b-value.

g. Calculate b-value, a-value, and return period by using the maximum Likelihood method and the Zmap 6.0 Matlab 2007Rb software program. This analysis used the best combination (95% - 90% - maximum curvature).

h. b-value was calculated for each grid point at constant radius containing 55 km. The value number of events used 20 so the result obtained is better and the study area is divided into grids with a size of 0.1° x 0.1°. The results calculation of b-values, a-values, and return periods are in the form of mapping.

4. Results and Discussion

4.1. Seismisitas Map of Bengkulu Province in Period 1960-2011

![Seismicity Map of Bengkulu Province](image)

**Figure 1.** Seismicity Map of Bengkulu Province
Figure 2. Map of Earthquakes (1960-2017) of Bengkulu Province

The earthquake data for the period 1960-2017 (57 years) obtained from the USGS catalog shows that the earthquake occurred in the province of Bengkulu with coordinates 1.1-6.3°SL dan 99.5-104.9°EL has 991 shallow earthquake events. After being clustered, these data become 796 events for shallow earthquake of depth 100 km with magnitude > 5 MW. The largest earthquake recorded occurred in 2007 with magnitude of 8.4 MW.

4.2. Distribution earthquakes of Frekuensi - Magnitude
The important parameters in the b-value and a-value is the Magnitude of Completeness (MC). From the frequency-magnitude distribution of earthquakes in the Bengkulu area (Figure 3), the magnitude of completeness value is 5.1. Using Maximum Likelihood estimation it was obtained that b-value and a-value are about 1.12-0.04 and 8.61.

Figure 3. Distribution of Frequenci-Magnitude

4.3. The Spatial of Variations b-value and a-value
The result of analysis is variations of $b$-values in the Bengkulu area ranging from 0.62 (Figure 4). The areas with relatively low $b$-values range from 0.6 to 1.2 located at the north of Bengkulu area (Agra Makmur), Muko-muko, Bengkulu city, Seluma (Tais) and Kepahiang and Rejang Lebong (Curup). The areas with relatively high $b$-values ranged from 1.2–2 located at the east and south of Bengkulu area, south Bengkulu (Manna), Lais, Kaur (Bintuhan), and lebong (Muara aman). The areas with low $b$-values have a higher potential for earthquakes with greater strength. This is understandable because areas with low $b$-values experience accumulated stress that has not been released.

4.4. The Spatial of Variations $a$-value

![Figure 4. Map of b-value](image)

![Figure 5. Map of a-value](image)
The result of analysis is variations of $a$-values in the Bengkulu. The spatial variation of $a$-values ranges from 5–13 (Figure 5). The areas with relatively low $a$-values ranging from 5-8 include the Bengkulu area of north (Agra makmur), Muko-muko, and area Kepahiang, Curup, Bengkulu city and Tais (Figure 6). And areas with relatively higher $a$-values ranging from 8-13 including south Bengkulu (Manna) Kaur District (Bintuhan) and Lebong (Muara-aman), show relatively high seismic activity. The spatial variations of $a$-values are similar to patterns of spatial variation of $b$-value.

4.5. Return period of earthquake

4.5.1. Return period of Magnitude 5 dan 5,5

![Figure 6. Magnitude 5](image)

![Figure 7. Magnitude 5,5](image)

The return period of earthquake with magnitude 5 MW (Figure 6) is 0.2 to 0.4 years including area of Kepahiang, Curup and the North Bengkulu. The return period of earthquakes with the range from 0.5 to 0.9 years includes area of the northern Bengkulu (Agra makmur), Mukomuko and Bengkulu city. The return period of earthquake with 5.5 MW magnitude (Figure 7) which is relatively large ranging from 1.5-3.5 years covers area of the northern Bengkulu area, Mukomuko, kepahiang, Bengkulu city and southern Bengkulu and all areas almost have magnitude 5,5 MW. For relatively small return period of earthquakes ranging from 3.5 to 6.5 years includes area the Lebong (Muara-aman).
4.5.2. Return period of Magnitude 6 dan 6.5

The return-period of earthquakes with magnitude 6 (Figure 8) ranges from 6 to 12 years relative quickly covering area of Muko-muko, the north Bengkulu (Agramakmur) and Bengkulu city, Tais and the southern Bengkulu. The areas that have relatively slow seismic opportunities are in Lebong (Muara-aman) and Bintuhan ranging from 12-18 years. For the magnitude of 6.5, the return period of earthquake area relatively fast ranging from 15 to 20 years including area of Mukomuko area, North Bengkulu (Agramakmur) and Bengkulu City. For the magnitude of 6.5 (Figure 9), the return period of earthquake area relatively fast ranging from 15 to 20 years including area of Muko-muko area, North Bengkulu (Agramakmur) and Bengkulu City.

4.5.3. Return period of Magnitude 7 dan 7.5

The return period of earthquake with magnitude 7 (Figure 10) ranges from 20-40 years including area of North Bengkulu (Agramakmur), muko-muko and Bengkulu city. And for magnitude 7.5, the return period of Earthquake ranging from 40-80 years with area Bengkulu City and Muko-muko (Figure 11)
4.5.4. Return period of Magnitude 8 dan 8.5

While the return period of Earthquake for magnitudes 8 and 8.5 (Figure 12 dan 13) including only area of the Bengkulu city and Kepahiang which ranges from 100-150 years.

5. Conclusions

Based on an analysis of the seismicity level and return period of Bengkulu Province in the period 1960 - 2017 it can be concluded that:

The variation of b-value which relatively low values ranges from 0.6 to 1.2 locates at the north of Bengkulu (Agra Makmur), muko-muko, Bengkulu city, Tais, Kepahiang and Rejang Lebong (Curup). While the variation of b-value which relatively high values ranged from 1.2–2 precisely locates in the east and south Bengkulu area, Lebong district (Muara aman), the south Bengkulu (Manna) and Kaur district (Bintuhan).

Area with relatively low a-values range from 5 to 8 include the north of Bengkulu area (Agra Makmur), Muko-muko, Kepahiang, Curup, Bengkulu city and Tais while the areas with relatively higher a-values range from 8 to13 are the bengkulu south (manna), Kaur district (Bintuhan) and Lebong district (Muara- aman) showing the level of seismic activity increasingly active.

The return period of earthquakes with magnitude of 5.5 ranged from 1.5 to 3.5 years is at almost all of Bengkulu areas, North Bengkulu, Muko-muko, Kepahiang, Curup, Bengkulu City and South Bengkulu, Tais and Bintuhan. And return period of earthquakes relatively small ranging from 3.5 to 6.5 years covers Lebong District area (Muara-amman).

The areas of North Bengkulu (Agra makmur), Kepahiang and curup, Bengkulu city, Tais occured the return period of earthquakes which relatively fast with more than magnitude 6 ranging from 6 to12 years.

The areas of north bengkulu (Agra Makmur), Muko- muko and Bengkulu city, Kepahiang, Curup have relatively high seismic activity and return period of earthquakes for magnitude of 7 – 7.5 ranging from 20-40 years and 40-80 years. For magnitude 8 and 8.5, return period ranging from 100-150 years includes only area Bengkulu city and Kepahiang- Curup.

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