Analysis of Seismicity Level in Central Sulawesi Period 1997 - 2017

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Abstract. Indonesia is located at an active tectonic zone, due to the encounter of three main slabs in the world: Eurasia, Pacific, and Indo-Australian slabs. This lead to high earthquake level in Indonesia, one of them is in Central Sulawesi. The research was conducted in order to identify the a value, b value, and seismicity using the Maximum Likelihood method. Earthquake data from the USGS catalog and BMKG were used from 1997 – 2017 with magnitude (M) ≥ 3 and depth (h) ≤ 1000 km, located at -30° S – 00° S and 118° E – 124° E. The result showed that highest seismicity is located at the Eastern part of Central Sulawesi. The Mc value of 5.2, a value ranges 5 – 11.5 indicates high seismic activity, b value ranges 0.6 – 1.8 indicates high level of rock fragility and rock resistance levels to low stress. The result in this study effectively to observe the seismicity which can be used as guided for earthquake mitigation.

1. Introduction

Indonesia is an earthquake-prone area which passed by the meeting pathway of three tectonic plates, the Indo-Australian Plate, the Eurasian Plate, and the Pacific Plate. The Indo-Australian Plate moves relatively North-ward and breaks into the Eurasian Plate, while the Pacific Plate moves relative to the West [1]. Plate meeting paths are in the sea, so that the large earthquake with shallow depth will also potentially cause a tsunami [2].

The inter-plate encounters that took place in Indonesia led to the complexity of Indonesian tectonics and the high level of seismicity. One of the areas with high seismicity is Central Sulawesi, whereas located close to the source of earthquake both on land and sea. The earthquake source of the sea comes from subduction in the north side of Sulawesi Island, while the source of earthquake on land is from several active faults in Central Sulawesi mainland, which is Palu Koro Fault [3].

Central Sulawesi is composed by the Pompangeo Complex, the limestones and the ofiolit. The Pompangeo complex is consist of schist, graphite, slate, genes, serpentinite, quartz and limestone bamboo. Pompangeo Complex rocks are included in rocks that have high seismicity. Based on the map in Figure 1, Central Sulawesi region composed of several faults [4]:

- **Palu Koro Fault**
  - This fault is found in South Sulawesi's North West-North-East Sulawesi.
- **Poso Fault**
  - The Poso Fault establishes a curved valley alignment with the metamorphic rock complex at the boundary and the South Sulawesi Mandala.
- **Wekuli Fault**
  - This fault is the boundary between the Complex Ofiolit of East Sulawesi and the metamorphic rock Complex of Central Sulawesi.
- **Matano Fault**
Matano Fault in land is characterized by the straightness of the valley that stretches from the Southeast Sulawesi Sea Beach, bypassing the Poso Rise in Central Sulawesi and finally joining the Palu Koro Fault.

- **Banggai Sula Block**
  Banggai Sula microcontinent is a fragment of the Australian continent thought to be separated from its parent continent in the Mesozoic era. Then, through the Sinistral mechanism of Sorong Fault, this microcontinent is transported westward. Until finally collide with East Sulawesi Arm in Central Miocene [5].

![Figure 1. Geological Map of Sulawesi Island [6]](image)

**2. Methods and Data**

The relation between frequency of earthquake occurrences with magnitude can be used to determine the number of earthquakes occurring in a region. This frequency and magnitude relationship produces b value (rock stress level) and a value (seismic activity). According to Gutenberg and Richter, The number of earthquakes (N) with magnitude (M) can be expressed by the following equation:

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

With \( \alpha = a - \log(b \ln 10) \)

- n (M) : the number of earthquakes that calculated from the occurrence.
- N(M) : the cumulative number of earthquakes is calculated on a certain scale.
- a : A constant that depending on the period, wide of an area and the activity at the focus area.
- b : Seismotectonic parameters, an area of an earthquake that depends on the nature of local rocks.
- M : Magnitude

Seismic statistics are one of the research subjects that have been conducted for the past twenty years. In 1944, Gutenberg-Richter stated that the distribution of earthquakes in an area throughout the observed range of events would follow a formula known as the Gutenberg-Richter relation equation 2 [7].
Figure 2. Relationship between Gutenberg-Richter which shows the relationship of logarithms of the number of earthquakes and magnitudes [7]

If the probability distribution function which depends on parameter b is \( f(M, b) \), then the likelihood function is defined as [8]:

\[
L(M, b) = f(M_1, b) \cdot f(M_2, b) \cdot f(M_3, b) \cdots (M_N, b)
\]

\( M_i \) and b are the magnitude and gradient parameters of equation 2.

The estimated maximum likelihood value of b can be determined by the formula:

\[
\frac{\partial \ln L}{\partial b'} = 0
\]

The \( M_i \) probability distribution function in the magnitude-frequency distribution is:

\[
f(M_i, b') = b' \cdot e^{-b'(M_i - M_0)}, M_i > M_0
\]

with \( b' = b \cdot \ln(10) \). Thus the sample likelihood function is:

\[
L = (b')^N \cdot \exp \left[-b' \left( \sum_{i=1}^{N} M_i - NM_0 \right) \right]
\]

Based on equation 6, estimation of maximum likelihood value of b is as follows [9]:

\[
b = \frac{\ln e}{M - M_0}
\]

The standard deviation of the value of b can be determined using the following formula [10]:

\[
\delta b = 2.30 b^2 \sqrt{\frac{\sum_{i=1}^{N} (M_i - \bar{M})^2}{N(N-1)}}
\]

Furthermore, the value of a can be estimated by the formula:

\[
a = \log N(M) + b \cdot (\ln 10) + bM
\]

ZMAP is an interactive software tool to investigate and visualize seismicity as a function of space and time made in 1994 by Stefan Wiemer. The main goal was to improve the resolution of potential seismicity anomalies and to study the overall characteristics of earthquake catalogs [11].

This research located at the Central Sulawesi region with coordinates -3\(^\circ\) S - 0\(^\circ\) S and 118\(^\circ\) E - 124\(^\circ\) E. Secondary data of earthquake occurrence in Central Sulawesi region at the period of 1997 - 2017 obtained from USGS and BMKG catalog.

Figure 3. Flow chart of this study
3. Results and Discussion

Based on Figure 5, the Central Sulawesi region has a very high seismicity rate that is spread over the land and sea. The source of earthquake in Central Sulawesi region is located in the sea due to Sangihe Subduction and a group of active faults on land.

The dominant incidence of earthquake occurrence is with depth below 237 km in eastern area of research. The more dominant earthquakes in the eastern part of the study (122.70 E - 1240 E and 00 S – 1.50 S) follow structures such as Sangihe and fault of Sorong. It is also in the center of the study (119.70 E - 120.70 E and 0.20 S – 1.50 S) of earthquakes caused by the Palu Koro fault, Poso Fault, and Wekuli Fault. In the southeast of the study area (120.70 E - 122.60 E and 20 S - 30 S) the earthquake distribution was caused by the Matano Fault. An earthquake with a depth of 237 <Z <790 is scattered around Central Sulawesi.

The most important parameter in determining the value of a and b is the magnitude of completeness (Mc). Mc values indicate that the existing seismograph network is capable of recording earthquakes at such magnitudes well. The value of Magnitude of completeness (Mc) in the study area as Figure 4 is 5.2. This means that the USGS and BMKG catalogs are capable of recording earthquakes with the smallest magnitude of 5.2. Based on the distribution of frequency magnitude, the value of b is 1.7. This high b value means that the Central Sulawesi region has a low level of stress, meaning that it has the chance of frequent earthquakes. From the calculation also obtained a value of 11.5 which means that the region of Central Sulawesi has a high level of seismic activity.

![Figure 4. Distribution Frequency of Magnitude and Mc Value](image)

Based on Figure 6, the southern Banggai Islands marked with dark blue and blue indicate that this area has low seismic activity. The areas of Palu, Majene, Morowali, East Luwu, West Banggai, Tojounauna, West Luwu Utara, East Poso, East Donggala, East North Mamuju are characterized by light blue and light green indicate that this area has high seismic activity. Yellow, orange and red in the South of Banggai, Banggai Islands, Eastern of Luwu Utara, Southwest Poso, South and Northwest Donggala, West North Mamuju indicate that the area has a high a value that indicated a highest level of seismicity. It has been proven that the number of earthquake events in this region over the past 20 years has been the magnitude of completeness of 5.2.
Figure 5. Distribution of Earthquake

Figure 6. The result of a value
Based on Figure 7 yellow, orange and red in South Banggai, Banggai Islands, Eastern of North Luwu, Southwest Poso, South and Northwest Donggala, West North Mamuju indicate that the area has a high \( b \) value around 1.31 – 1.8 is caused by the present of volcanic rocks, plutonic rocks, rocks crust influenced by Palu-Koro Faults, Sorong Fault, and Sangihe Subduction.

The area of Palu, Majene, Morowali, East Luwu, West Banggai, Tojounauna, Western of North Luwu, East Poso, East Donggala, East North Mamuju characterized by light blue and light green indicates that this area has a fairly high \( b \) value of about 1.2 - 1.3 this is because in this area composed of sedimentary rocks, carbonate rocks, metamorphic, ultramafic, volcanic, schist, ophiolit passing by Palu-Koro active fault, Positive Fault Poso, Fault Matano shows high level of rock fragility and power level rock resistance to low stress. The southern Banggai islands marked with dark blue and blue indicate that this area has a low \( b \) value of about 0.6 to 1.1 is the result because the area is not passed by the faults.

![Spatial Variation b Value 1997-2017](image)

**Figure 7.** The result of \( b \) value

### 4. Conclusions

Based on the results and discussion, we had beconclude that:

1. The highest level of seismicity is in the eastern part of Central Sulawesi region, this is caused by the activity of Sangihe Subduction and Sorong Fault. The central region of the study was due to the Palu Koro Fault, Poso Fault, and Waikuli Fault. The south-eastern part of the study was caused by the Matano Fault.

2. Spatial variation of \( a \) value in the Central Sulawesi region ranges from 5 to 11.5, the region with the highest \( a \) value of South Banggai, Banggai Islands, Eastern of North Luwu, Southwest Poso, South and Northwest Donggala, Western of North Mamuju. The spatial variation of \( b \) value in the Central Sulawesi region ranges from 0.6 to 1.8, the region with the highest \( b \) value being South Banggai, Banggai Islands, Eastern of North Luwu, Southwest Poso, South and Northwest Donggala, Western of North Mamuju.
In the next step, the study will continue for determining hypocenter to get more accuracy in this result. The result in this study effectively to observe the seismicity which can be used as guided for earthquake mitigation.

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