Seismicity analysis Sulawesi North Arm based on B-Value

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Abstract. Sulawesi is one of the areas with high population. One of which is around the provinces of Gorontalo and North Sulawesi, in terms of geology, it is in the northern arm of Sulawesi. Some natural disasters lurk the population in this area, which is earthquake. B-value research are conducted to add information and insight in preparing hazard mitigation steps in this area. The data used are derived from BMKG throughout the years 1904 – 2014. Low B-value is in the sea area. The district of Gorontalo and Bolaang Mangondow indicated low fragility of the rock and high stress durability. In contrast, the highest b-value is at around Una-Una Volcano. Seismicity on this area caused by several fault lies beneath Sulawesi North Arm such as Gorontalo Fault and Sulawesi Double Subduction. The results can show that the concept of spatio-temporal anomaly in the b-value are statistically significant and carries important information on practical estimates related to hazard mitigation.

1. Introduction

Sulawesi is one area with high population density. This condition caused by many ethnic who stay on this area. Transmigration program added population on Sulawesi. But, there are several natural hazard potential on this area. One of them is earthquake.

Sulawesi North Arm is one of part in Sulawesi which have unique geology condition. Tectonic activity from Sulawesi Sea Subduction, Gorontalo Fault, Molucca Sea Double Subduction and Palu-Koro Fault caused high seismicity at this area [1]. One of which is around the provinces of Gorontalo and North Sulawesi. Some natural disasters lurk the population in this area. B-value research are conducted to add information and insight in preparing hazard mitigation steps in this area. B-value study give information about rock brittleness and return period of earthquakes.

B-values are empirical value of earthquake which varies based on its hypocenter and magnitudes with seismo-tectonic implications. This parameter is associated with several conditions such as regional tectonics, the structural heterogeneity of the crust, the stress distribution. B-value depends on the fault mechanism and thermal gradient. Changes in pure-pressure can influence the b-value. High b-values are associated with have a lot weak earthquakes, while low is related to fewer of stronger earthquakes [2].

In the former research, low b-value shows area with densely faults of or higher fracture rates or relatively high stresses. Thermal gradient also have a positive correlation between the b-value. Several research looking at low b-values for asperities in the crust can indicate an increase in the degree of stress, perhaps due to the material homogeneity in the crust. The intermediate b-values zone may be a reference to area facing high thermal gradients due to either thermal upwelling above the heat source or a sign of the effect of geothermal remaining after past volcanic activity. High b-values are reported to the existence of active magmatic objects placed in the crust, the source of which may be located in the lithospheric mantle [3]. In many continental zones, an increase in depth is followed by a decrease in the b-value that has been assumed as a result of increasing crust strength, and material homogeneity with depth [4].

In the laboratory, the b-values changes systematically with respect to various control factors. These include the degree of material heterogeneity, the level of stress applied, the degree of stress concentration, i.e. the normalized stress intensity of fracture toughness, chemical reactivity from pore fluids, and pore fluid pressure. In nature other factors that influence the b-value systematically include the focal mechanism, depth, and the degree of coupling or strain partition between seismic and aseismic deformation at plate boundaries [5]. The expected results can show that the concept of spatio-temporal anomaly in the b-value are statistically significant and carries important information on practical estimates related to hazard mitigation. [6].

2. Methods and Data

The first step is determining magnitude of completeness (Mc). The Mc is the complete minimum record of earthquakes in the study area, such as the dataset including events with the minimum Mc will get the most precise b-value. The cumulative frequency magnitudes is the basis of predicting Mc. Mc can be calculated using estimation methods such as the maximum curvature, the entire-magnitude-range (EMR), and other methods. At present these methods are widely accepted, including the best combination method, is: [2].

$$\text{Mc95} - \text{Mc90} - \text{maximum curvature} \quad \ldots (1)$$

95Mc and 90Mc show 95% and 90% goodness-of-fit values calcuted by the maximum likelihood method, respectively, and maximum curvature shows Mc calculated from the maximum curvature method. The Mc chosen must be homogeneous in space and time [2].

Relation between earthquake frequency and magnitude showed in an empirical equation [2, 3, 5, 6, 7]:

$$\text{Log } N(M) = a - bM \quad \ldots (2)$$

N(M) is the earthquake cumulative number with a magnitude greater than the target magnitude M, and a and b are two positive constants, where a (a-value) informed level of seismicity with range 2 to 8 and b (b-value) show the gradient of the cumulative number relative to the magnitude trend range from 0.5 - 1.5 [2]. The b-value describes the attribute of seismicity in area. The Frequency Magnitude Distribution method (FMD) is one of the method that can be taken to research about the material properties at depth (e.g. heterogeneity) [3]. In a semi-logarithmic graphic, the a- and b-value can be estimated. A High b-value signs an increase in material heterogeneity or fracture density whereas low b-value indicates a high shear stress. B-value is interpreted to describe the presence of an asperity, stress rank and material heterogeneities along the fault plane [6].

The b-value also indicates the catalogue relative proportion to weak and strong events. At present the method often used in calculating b-value is the Maximum Likelihood Method (MLM), is [2, 3, 4, 5, 6].

$$b = \frac{\log e}{\left[(\bar{M}) - \left(M_C - (\Delta M_{bin}/2)\right)\right]} \quad \ldots (3)$$

Mc is the magnitude of completeness, $\bar{M}$ is the average magnitude of events with a magnitude of M $\geq M_C$, and ΔM is the binning interval of the magnitude [4]. The MLM considers equally and correctly for each earthquake and allows for the structure of data errors: in a Poisson distribution of frequency data [5]. B-value shows relation between weak and strong event and it is related to the tectonic heterogeneity of the asperity area. The theory of asperity consists of locked parts that resist faulting [6].

The FMD method can resolve Mc temporal changes. We determine Mc as a function of time for the whole period using a Moving Window Approach. We can get the temporal behavior of completeness using the FMD method as a reference [6].

Mc determination using ZMAP code [8]. Earthquake hypocenter data onto 1904 – 2014 got from BMKG (Indonesia Agency of Meteorology, Climatology and Geophysics) Catalog. The data use as input to get a- and b-value in this research. Value will be mapped and analyzed.

3. Results and Discussion

Epicenter distribution at Sulawesi North Arm showed high seismicity at this area (Figure 1). Epicenter focused nearby coast at northern and southern of Sulawesi North Arm. This caused by several structure such as Sulawesi Sea subduction, East Sangihe thrust and Gorontalo Fault in eastern, southern and lies on Sulawesi North Arm [9].

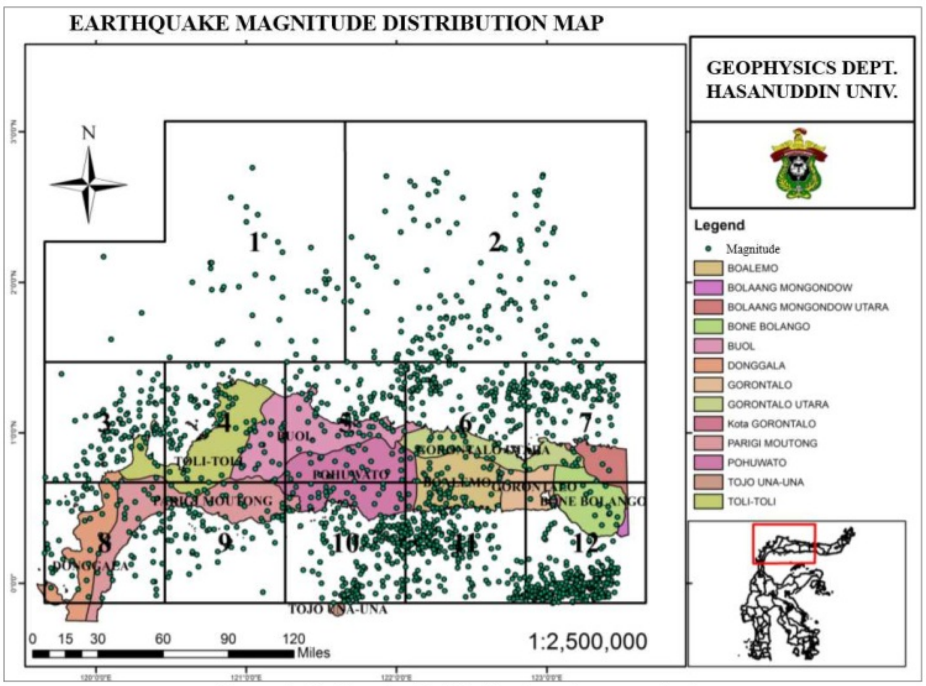

Figure 1. Earthquake distribution based on magnitude.

Magnitude – frequency distribution earthquake at Sulawesi North Arm showed frequency decreased meanwhile magnitude increased. Frequency – magnitude distribution (Figure 2) drawing relation between magnitude and earthquake number occurred. In here, this curve gives Magnitude of Completeness (Mc) accurately from observed data onto power-law distribution assumption. Mc values in Sulawesi North Arm of BMKG Catalog is around M5.3. This Mc value informed that BMKG Catalog contained only relative-strong earthquake.

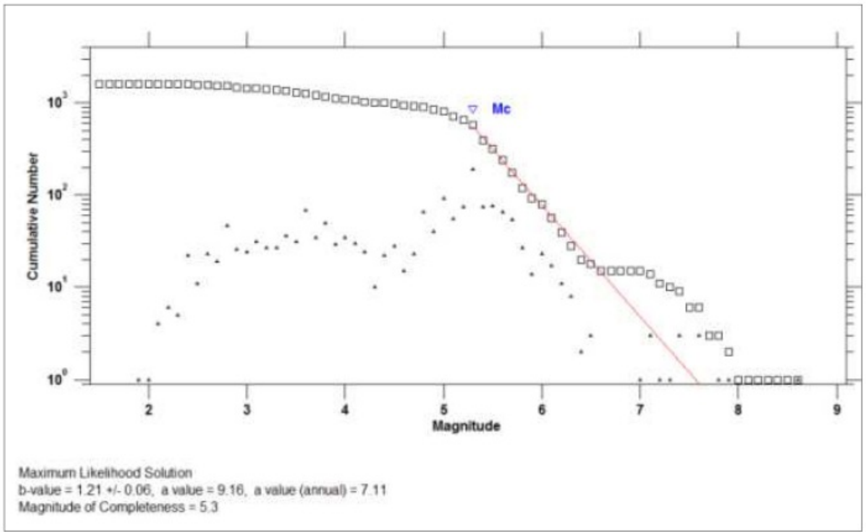

Figure 2. Frequency – magnitude distribution with maximum likelihood methods.

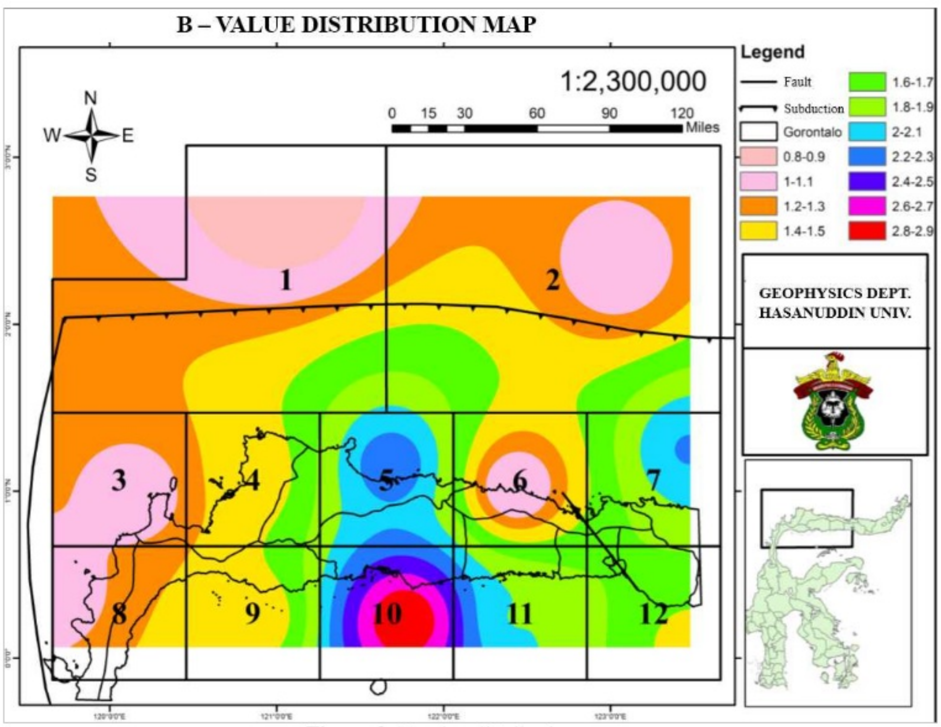

Figure 3. B-value distribution map.

Grid sizes made easy about interpretation. High B-value had high rock brittleness level and low endurance level to stress, and the opposite [10]. On Figure 3, based on calculation result, the highest B-value lies on area 10, with Una-una active volcano, with coordinate 121.259^0 – 122.059^0 E and 0.67^o – 0.13^0 N is 2.7667. This area has an earthquake frequency (N) 86 with average magnitude are 5.4. Low B-value lies on area 1, 2, 3, 6 and 8 covered sea, Gorontalo regency and Bolaang Mangondow regency is 0.808 - 1.1035. And for b-value range 1.184 - 1.9799 covered sea and land is area 4, 5, 7, 9, 11 and 12.

Low values lie in the seismically active tectonic zone. The seismicity zone related to reverse mechanisms shows b-values range 0.6 – 1.0, while the strike-slip fault zone displays b-values range 0.5 – 1.0. The area with fault mechanism both reverse and strike-slip components show b-values more than 0.85. This condition is similar with other research, such as research on the Middle East. The lowest b-values are reverse fault while intermediate b-values are strike-slip fault. The highest b-values are normal or combinations of reverse and strike-slip fault [6]. Based on that information, seismicity on this area caused by several fault lies beneath Sulawesi North Arm such as Gorontalo Fault (strike-slip fault) and Sulawesi Double Subduction (reverse fault).

High accumulation of stress, signed by low b-values, is related to a high seismic moment release. Then, in the research area have a high probability of earthquake because related to the high stress accumulation part. The low b-values signed the high level of compressional stress in the area due to the frictional conditions of the heterogeneous structure. The seismo-tectonic setting of the research area can learned from b-values as an indirect stress meter. So, b-values are used as references of different structures of the subduction zone in variable part [6].

4. Conclusions

B-value distribution at Sulawesi North Arm showed hazard potency at this area if earthquake occurred. The highest B-value lies on area 10, with Una-una active volcano. Low B-value lies on area 1, 2, 3, 6 and 8 covered sea, Gorontalo regency and Bolaang Mangondow regency. Seismicity on this area caused by several fault lies beneath Sulawesi North Arm such as Gorontalo Fault and Sulawesi Double Subduction. The results can show that the concept of spatio-temporal anomaly in the b-value are statistically significant and carries important information on practical estimates related to hazard mitigation

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