Classification of Earthquake Distribution in the Banda Sea Collision Zone with Point Process Approach

Henry J. Wattimanela, Udjianna S. Pasaribu, Nanang T. Puspito, Sapto W. Indratno

***Abstract*—**Banda Sea Collision Zone (BSCZ) is the result of the interaction and convergence of Indo-Australian plate, Eurasian plate and Pacific plate. This location is located in eastern Indonesia. This zone has a very high seismic activity. In this research, we will calculate the rate (λ) and Mean Square Error (MSE). By this result, we will classification earthquakes distribution in the BSCZ with the point process approach. Chi-square is used to determine the type of earthquakes distribution in the sub region of BSCZ. The data used in this research is data of earthquakes with a magnitude ≥ 6 SR for the period 1964-2013 and sourced from BMKG Jakarta. This research is expected to contribute to the Moluccas Province and surrounding local governments in performing spatial plan document related to disaster management.

***Keywords*—**Banda sea collision zone, earthquakes, mean square error, Poisson distribution, chi-square test.

I. Introduction

TECTONIC earthquake is one of the natural disasters that are feared by humanity, because it causes great losses. Tectonic earthquakes usually occur at the interface between the two plates. The tectonic plates are always moving and mutually press each other. The movement of tectonic plates causes energy accumulation slowly. Later tectonic earthquakes occur due to the release of energy that has long been stored it. Tectonic earthquakes often found in Indonesia at subduction Banda (Banda Sea region), Banda Collision Zone and Papua [1], [2]. Research on the distribution of earthquakes with statistical science approach has been made by many researchers related magnitude aftershocks, earthquakes with great strength and observation time between earthquakes [3], [4]. On the other hand, the application of the concept of the point process, which is part of stochastic processes have been developed to observe and describe various aspects of the field, among others, forestry, geology, ecology and seismology [5]-[8]. Especially in the field of seismology, the application process has been done related point characteristics and patterns of occurrence of earthquakes. Application of the point process to the case of earthquakes has been conducted by researchers associated earthquake aftershock and multi-dimensional residual analysis [9]-[11], and fractal characterization of the spatial distribution [8]. The application process has not been applied to the local point BSCZ particularly related to a distribution model that a large magnitude earthquakes. Due to the current research in this area is more emphasis on the case of seismology as discussing the structure of the area of the collision on BSCZ [11]-[14], related to the depth of the area BSCZ [15]-[18], and the tectonic activity of the arc Banda in BSCZ [19], [20].

In this research, we apply the theory of stochastic counting processes for classification earthquake distribution of earthquakes with magnitude ≥ 6 SR for period of 50 years (1964-2013) at each partition area (30 locations) of BSCZ region.

This article consists of an introduction, results, and discussion including the location and observation data, methods and distribution models and experimental results, which ended with the conclusion. This research is expected to contribute the development of statistical science and the Moluccas Province and surrounding local governments in performing spatial planning taking into account disaster management.

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II. Result and Discussion

A. Location and Data Observations

In BSCZ represents an outstanding example of active arc-continent collision and one of the most tectonically complex and seismically active areas on earth and it is characterized by some peculiarities that make the region unique among other zones of convergence [26]. BSCZ region bounded by 2^0 LS - 7^0 LS and 126^0 BT - 132^0 BT. BSCZ region consist some islands: Buru, Ceram, and part of the Banda Sea (Fig. 1). The data used in this study was the incidence of earthquakes in 1964-2013 in BSCZ with magnitude ≥ 6 SR and it can be obtained on BMKG Jakarta-Indonesia (website). The number of earthquakes per year for the years 1964-2013 can be shown in Fig. 2.

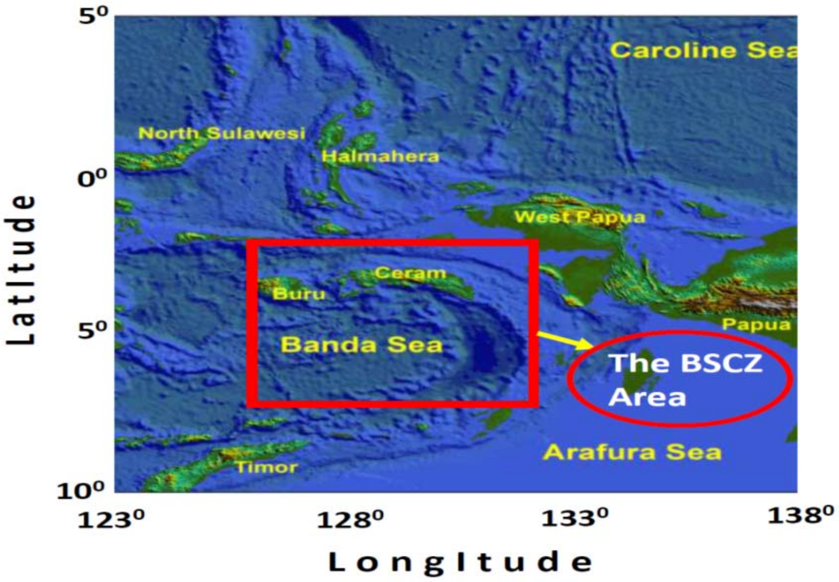


Fig. 1 Location of BSCZ Region in Moluccas Area

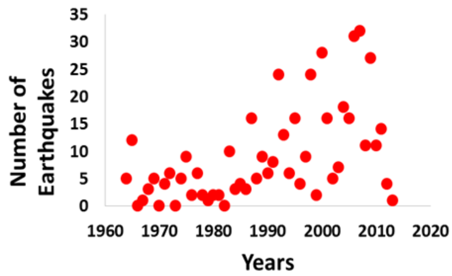


Fig. 2 Number of earthquakes BSCZ Region per years (1964-2013)

B. Research Methods

In this study, the partitioning method used to form the set of models that is congruent with the approach of partitioning the set square. Partitioning is a representation of a set of disjoint regions. We suppose that $A \subseteq R^d$, $d = 1,2,3$ and finite partition of set A denoted by ϑ is a collection of disjoint subset A_i, $i = 1,2,..,n$, or $\vartheta = \{A_i\}$, where $A_i \subset A$ and $A_i \cap A_j = \emptyset$ for $i \neq j$. Point processes $\{N(A), |A| \geq 0\}$ is stochastic process with the realization as counting process if $N(A)$ is stating the number of events that occur on any set A [9], [21]. Let $N(A)$ denote the number of earthquakes in A. Then $N(A)$ Poisson distribution with λ expressed rate earthquakes occurring per unit area location partition:

$$P(N(A) = y) = \frac{e^{-\lambda|A|}(\lambda|A|)^y}{y}, y = 0,1,2, ... , \quad (1)$$

$|A|$ is area size of A. Partitions that will be used in this study are congruent square models and process can be done by doing the arithmetic sum of all events within each subset. Since $A_i \cap A_j = \emptyset$, $i \neq j$, and $A = \cup_{i=1}^{n} A_i$, $N(A) = N(\cup_{i=1}^{n} A_i) = \sum_{i=1}^{n} N(A_i)$; where $N(A_1)$, $N(A_2)$, …, $N(A_n)$ are independent random variables [27]. The other side $\lambda = \hat{\lambda} = \frac{\sum_{n=0}^{k} n.f_n}{n}$, $k = 0,1,..,r$ with f_n is the location frequencies of n earthquakes. We applied MSE to see the degree of closeness between observed and expected value. $MSE = \frac{\sum_{n=0}^{k} f_n(\hat{Y}_n - Y_n)}{\sum_{n=0}^{k} f_n}$, $k = 0,1,..,r$ where Y_n is result of observation nth and $\hat{Y}_n$ is result of expectation nth. To test whether the data the number of earthquakes follow a Poisson distribution, we apply the Chi-Square test. In this test the null hypothesis H_0 is data number of earthquakes follow a Poisson distribution. H_0 is reject if chi-square calculation (χ^2_{calc}) > chi-square table (χ^2_{table}) [22].

C. Case Study

BSCZ observation area is partitioned into 30 sub regions with each of the length and width of 1 degree (1^0) as show in Fig. 3.

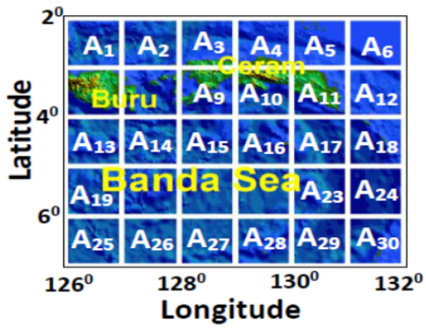


Fig. 3 Partitions Area of BSCZ Region (30 Locations)

The distribution of earthquakes from the year 1964-2013 can be seen in Fig. 4.

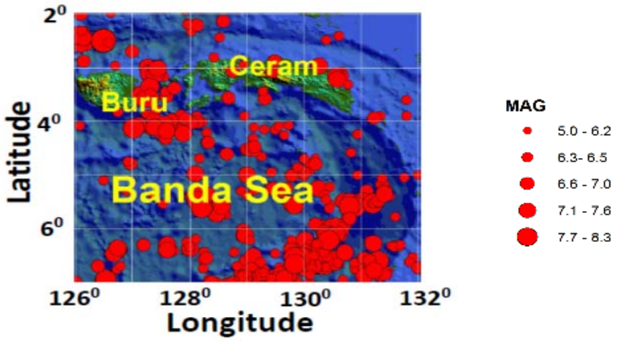
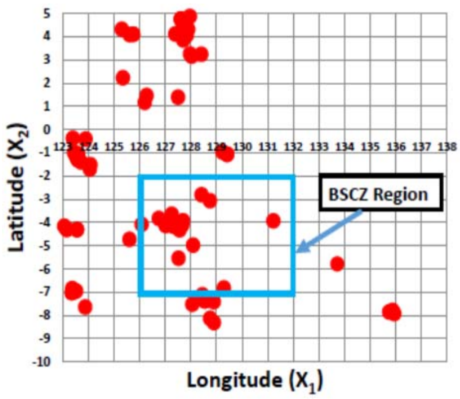


Fig. 4 Earthquakes Distribution with Mag ≥ 6 SR in BSCZ Region (1964-2013). Earthquakes (Mag ≥ 6 SR mostly occur in the area bounded 3^0 LS - 5^0 LS & 127^0 BT - 128^0 BT and 5^0 LS - 7^0 LS & 128^0 BT - 132^0 BT

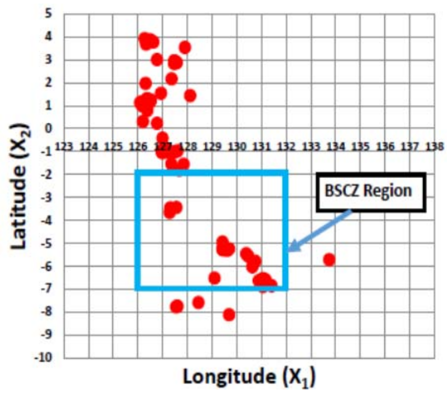
Determination of the set of the partitions on the BSCZ regions is used to avoid repeating calculation of an event happening earthquake on a different partition regions. We partition the BSCZ region into 30 sub regions in the following way:

$$A_{0+k} = \{(x_1, x_2)|\ 125 + k \le x_1 < 126 + k;\ -3 < x_2 \le -2\}$$
$$A_{6+k} = \{(x_1, x_2)|\ 125 + k \le x_1 < 126 + k;\ -4 < x_2 \le -3\}$$
$$A_{12+k} = \{(x_1, x_2)|\ 125 + k \le x_1 < 126 + k;\ -5 < x_2 \le -4\}$$
$$A_{18+k} = \{(x_1, x_2)|\ 125 + k \le x_1 < 126 + k;\ -6 < x_2 \le -5\}$$
$$A_{24+k} = \{(x_1, x_2)|\ 125 + k \le x_1 < 126 + k;\ -7 \le x_2 \le -6\}$$

where k = 1, 2, 3, 4, 5, 6; $|A_1| = |A_2| = \cdots = |A_{30}| = 1$ per unit area. The earthquakes distribution in BSCZ region for years 2000 and 2007 are given in Fig. 5. Based on Fig. 3, $A = \bigcup_{i=1}^{30} A_i$, and $N(A) = N(\bigcup_{i=1}^{30} A_i) = \sum_{i=1}^{30} N(A_i)$. In this research, we assume that the random variables of $N(A_1), N(A_2)$, …, $N(A_{30})$ are independent. The calculation will be done $\hat{\lambda}$ dan MSE for earthquakes each 30 locations for 50 years period (1964-2013). Calculation of MSE preceded by calculating observation and expectations of data by using (1) for a lot of earthquakes per 30 locations to 50 years. Based on data, sub regions A_6 and A_{18} have not earthquake with a Mag ≥ 6 SR. $\hat{\lambda}$ and MSE of 30 locations are given in Table I.



(a) Scatter plot of earthquakes in year 2000. Earthquakes (Mag ≥ 6 SR) mostly occur in the area bounded 2^0 LS - 6^0 LS and 126^0 BT - 129^0 BT



(b) Scatter plot of earthquakes in year 2007. Earthquakes (Mag ≥ 6 SR mostly occur in the area bounded 4^0 LS - 7^0 LS and 128^0 BT - 132^0 BT

Fig. 5 Earthquakes Distribution with Mag ≥ 6 SR in BSCZ Region

TABLE I
THE RESULTS OF CALCULATIONS OF $\hat{\lambda}$ AND MSE

Sub Region	$\hat{\lambda}$	MSE	Sub Region	$\hat{\lambda}$	MSE
A_1	0.24	0.01252	A_{16}	0.44	0.02871
A_2	0.08	0.00137	A_{17}	0.12	0.00283
A_3	0.14	0.00111	A_{19}	0.64	6.97E-07
A_4	0.04	0.00036	A_{20}	0.04	6.97E-07
A_5	0.06	3.66E-06	A_{21}	0.36	0.03905
A_7	0.02	4.18E-08	A_{22}	0.32	0.03549
A_8	0.66	0.09006	A_{23}	0.56	0.03207
A_9	0.14	0.00099	A_{24}	0.44	0.04314
A_{10}	0.10	0.00127	A_{25}	0.36	0.02750
A_{11}	0.12	0.00514	A_{26}	0.20	0.00387
A_{12}	0.08	1.2E-05	A_{27}	0.56	0.05493
A_{13}	0.08	0.00032	A_{28}	1.04	0.02339
A_{14}	0.42	0.07659	A_{29}	1.56	0.09884
A_{15}	0.20	0.00651	A_{30}	0.64	0.07574

Based on Table I, it is seen that there is no calculation of $\hat{\lambda}$ and MSE for the location of the A_6 and A_{18} because there are no earthquakes with magnitudes ≥ 6 SR during the years 1964 to 2013. It shows that $\hat{\lambda}$ for location A_{29} (part of the Banda Sea) is greater than other location because the highest number of earthquakes in the area BSCZ that occurred in the year that is equal to 78 earthquakes with strength magnitude ≥ 6 SR. Otherwise A7 has the smallest value of $\hat{\lambda}$ and the location is located on Buru Island. The other sub regions such as A_2, A_{12}, & A_{13}; A_3 &A_9 ; A_4 & A_{20}; A_{11} & A_{17}; A_{15} & A_{26}; A_{16} & A_{24}; A_{19} & A_{30} ; A_{21} & A_{25}; and A_{23} & A_{27} have the same value of $\hat{\lambda}$ (Fig. 6). Also based on Table I sub regions $A_{29,}$ it has the largest MSE value and location A_7 has the smallest MSE value. Fig. 7 shows that the graph of the expectations and observation data for some locations having Poisson distribution. Therefore, we divide on two classes based on proximity graphs observations and expectations that are close and not close. Based on Fig. 7 (a), it is seen that the expectation graphs in A_2, A_3, A_9, A_{10}, A_{13}, and A_{15} are close with the observation graphs. On the other side, the expectation and observation graph in A_8, A_{16}, A_{23}, A_{24}, A_{27} and A_{29} are not close as show in Fig. 7 (b).

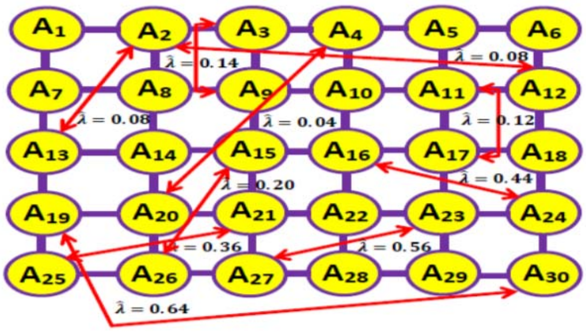
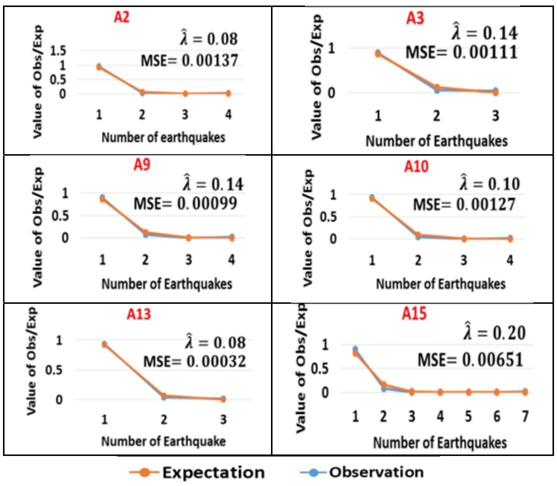
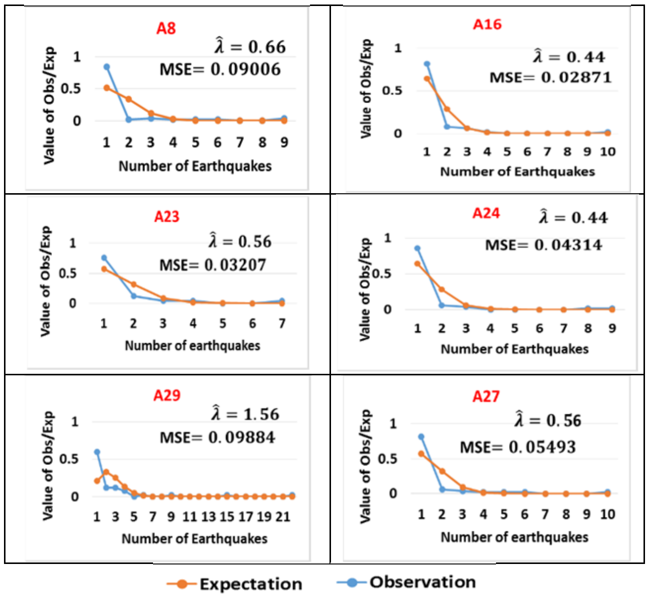


Fig. 6 Graph of linkages between locations that have the same $\hat{\lambda}$ value

The results expectations and observations graph is as show in Fig. 7, it can be presumed that the data follow a Poisson distribution. We test whether the data of 28 locations (partitions) follow a Poisson distribution by the chi-square test. Based on calculation result, χ^2_{calc} for data of earthquakes A_1-A_{30} for 50 years of BSCZ region and its result that χ^2_{table}= 40.113 (n = 28, α = 0.05), show that 13 locations (43%) is $\chi^2_{calc} < \chi^2_{table}$ of 28 locations. This means that H_0 is accepted for 13 locations (A_1-A_5, A_7, A_9, A_{10}, A_{12}, A_{13}, A_{19}, A_{20}, and A_{26}) of data earthquakes, so we can be said that the earthquakes data to follow a Poisson distribution (Table II).



(a) Graphs of Observation and Expectation data locations are close



(b) Graphs of Observation and Expectation data locations are not close

Fig. 7 Graphs of Observation and Expectation data locations are close and not close

TABLE II
THE RESULTS OF CHI-SQUARE CALCULATION

Sub Region	χ^2_{calc}	Sub Region	χ^2_{calc}	Sub Region	χ^2_{calc}
A_1	6.217557	A_{12}	0.0025330	A_{23}	133.86560
A_2	5.147991	A_{13}	0.1439085	A_{24}	18809.782
A_3	0.375105	A_{14}	3.566E+16	A_{25}	34672047
A_4	0.499995	A_{15}	5496.8068	A_{26}	7.6623401
A_5	0.000804	A_{16}	364620.87	A_{27}	46924.300
A_7	9.973E-68	A_{17}	52.391166	A_{28}	2782.0113
A_8	6943.0002	A_{19}	0.0001592	A_{29}	8.556E+14
A_9	1.0722449	A_{20}	0.0001592	A_{30}	410379998
A_{10}	2.7331167	A_{21}	17387383		
A_{11}	52.476994	A_{22}	17754052		

Poisson distributed locations (13 locations) can be mapped on BSCZ region as shown in Fig 8.

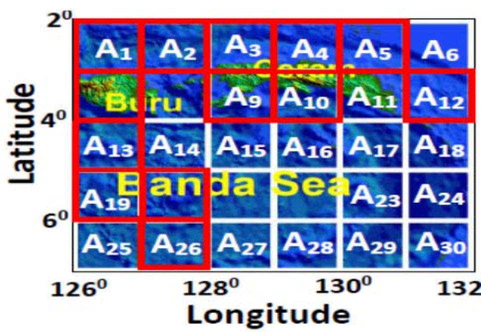


Fig. 8 The Mapping Poisson Distribution in Partition Area of BSCZ region

Fig. 8 shows that the location of the earthquake (Mag ≥ 6 SR) Poisson distributed in the area 2^0 LS - 4^0 LS & 126^0 BT - 129^0 BT and 4^0 LS - 7^0 LS & 126^0 BT - 128^0 BT. This area consist of the islands: Buru, Ceram, also included are some locations in the Banda Sea. We will be calculated λ and MSE value from the combination of several locations in the region BSCZ which has the same $\hat{\lambda}$ of earthquake occurrence based on Table I. Suppose location B_1 is result the combined of locations A_2, A_{12}, and A_{13}. The same way for location A_3 & A_9 = B_2; A_4 & A_{20} = B_3; A_{11} & A_{17} = B_4; A_{15} & A_{26} = B_5; A_{16} & A_{24} = B_6; A_{19} & A_{30} = B_7; A_{21} & A_{25} = B_8; and A_{23} & A_{27} = B_9. The results calculation λ and MSE in detail can be shown in Table III.

TABLE III
THE RESULTS OF CALCULATIONS $\hat{\lambda}$ AND MSE

Sub Region	$\hat{\hat{\lambda}}$	MSE	Sub Region	$\hat{\hat{\lambda}}$	MSE
B_1	0.24	0.00571	B_6	0.88	0.66459
B_2	0.28	0.00469	B_7	0.68	0.07486
B_3	0.08	0.00032	B_8	0.62	0.08179
B_4	0.24	0.01695	B_9	1.12	0.06177
B_5	0.40	0.01129			

We test whether the data of 9 locations follow a Poisson distribution using the chi-square test (Table IV).

TABLE IV
THE RESULTS OF CHI-SQUARE CALCULATION

Sub Region	χ^2_{calc}	Sub Region	χ^2_{calc}
B_1	0.925009	B_6	8865.462612
B_2	0.718871	B_7	2192460.614
B_3	0.143905	B_8	5723704.621
B_4	81.422225	B_9	181.605093
B_5	106.442538		

Based on calculation result, χ^2_{calc} for data of earthquakes B_1-B_9 (includes locations of A_1, A_5, A_7, A_8, A_{10}, A_{14}, A_{22}, A_{28}, and A_{29}) for 50 years of BSCZ region and its result that χ^2_{table}= 27.587 (n = 18, α = 0.05), show that 7 locations (38.9%) is $\chi^2_{calc} < \chi^2_{table}$ of 18 locations. This means that H_0 is accepted for 7 locations (B_1-B_3, A_1, A_5, A_7, and A_{10},) of data earthquakes, so we can be said that the earthquakes data to follow a Poisson distribution.

III. CONCLUSION

There are two sub regions of BSCZ that do not have earthquakes with Mag ≥ 6 SR during periods 1964-2013, namely A_6 (near Ceram) and A_{18} (part of Banda Sea). In addition, there are some sub regions of the BSCZ region which have the same value of λ, and there are two sub region which have the smallest and largest value of λ, namely A_7 (part of Buru) and A_{29} (part of Banda Sea). The other sides, the data number of earthquakes in the BSCZ Poisson distributed as much as 43% in some location such as Buru, Ceram, and also some location of the Banda Sea. The location of known types of this distribution will facilitate the prediction of earthquakes in advanced research. The other side, this results could be used by the Moluccas Province government as one of the references in preparing spatial Moluccas Province taking into account the risks related to disaster management and mitigation, including the development of infrastructure related to the strength of the building.

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