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Earthquake Classification in Molluca Collision Zone Using Conventional Statistical Methods

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***Abstract*—**Molluca Collision Zone is located at the junction of the Eurasian, Australian, Pacific and the Philippines plates. Between the Sangihe arc, west of the collision zone, and to the east of Halmahera arc is active collision and convex toward the Molluca Sea. This research will analyze the behavior of earthquake occurrence in Molluca Collision Zone related to the distributions of an earthquake in each partition regions, determining the type of distribution of a occurrence earthquake of partition regions, and the mean occurence of earthquakes each partition regions, and the correlation between the partitions region. We calculate number of earthquakes using partition method and its behavioral using conventional statistical methods. In this research, we used data of shallow earthquakes type and its magnitudes ≥4 SR (period 1964-2013). From the results, we can classify partitioned regions based on the correlation into two classes: strong and very strong. This classification can be used for early warning system in disaster management.

***Keywords*—**Molluca Collision Zone, partition regions, conventional statistical methods, Earthquakes, classifications, disaster management.

I. Introduction

To the Moluccas, the tectonic earthquake vulnerability is often categorized as a special area because it is a confluence of 3 major tectonic plates, respectively Eurasian, Indian-Australian, and Pacific [1]. In the Moluccas, there is some collision zone one is Molluca Collision Zone (MCZ) and its location at corcourse of the Eurasian, Australian, Pacific and the Philippines plates. So, in the east of Halmahera arc is active collision, convex toward the Maluku Sea and the Sangihe arc in west of the collision zone, [2]-[4]. This collision formed a complex structure in North Sulawesi arc [5]. Seismic activity in subduction system MCZ has resulted in asymmetric double dip. Seismicity along the Benioff zone extends to a depth of 300 km below the Halmahera arc. Under the Sangihe arc, Beniof Zone at Sea Plate Molluca extends more than 600 km, indicating that long-lived subduction system [6]-[9]. MCZ has been discussed with relation to crustal structure and tectonics of the Molluca Sea Collision zone Indonesia [10], lithospheric deformation within the Molucca sea arc-arc collision-evidence from shallow and intermediate earthquake activity [11], seismic-wave propagation beneath the Molucca Sea arc-arc collision zone, Indonesia [12], earthquakes and ophiolite emplacement in the Molucca Sea Collision zone, Indonesia [13]. This research will be reviewed in the event of an earthquake behavior previously MCZ be partitioned into several sub-regions. The behavior of the MCZ earthquakes associated with the distribution of earthquakes including earthquakes distribution type for each partition. In determined type of distribution of each partition region can be approximated by using the Kolmogorov-Smirnov test. While the average earthquake occurrence for each partition area will be approached by using one-way ANOVA, and correlations between the partition regions approximated by using the concept of correlation [14]. In this study, the partition is a partition that is used to form the set of models is congruent with the approach of partitioning the set square. Partitioning is a representation of the sets is disjoint. Suppose the set $A \subseteq R^d$ with $d = 1,2,3$. Suppose a finite partition of the set A denoted by ϑ is a collection of subsets A_i for $i = 1,2,..,n$ to each other independent or $\vartheta = \{A_i\}$, $i = 1,2,..,n$ with $A_i \subset A$ and $A_i \cap A_j = \emptyset$ for $i,j = 1,2,..,n$, $i \neq j$. The combination of a sub set of A_i the generating set A itself and can be written as $A = \bigcup_{i=1}^{n} A_i$ with $A_i \cap A_j = \emptyset$ the for $i,j = 1,2,..,n$, $i \neq j$. Partition will be used with unvarying form. The process of counting events in the set can be done by summing the results of the counting of events in each sub-set. This means that $N(A) = N(\bigcup_{i=1}^{n} A_i) = \sum_{i=1}^{n} N(A_i)$ [15]. The data used is the data type of shallow earthquakes [16] with magnitudes ≥4 SR [17] for the period 1964-2013 in the Molluca Collision Zone. The results of this research can be used as one of the early warning systems related to earthquakes in the MCZ that can help local governments with regard to disaster mitigation.

II. Result and Discussion

A. Determination of Partition in Observations Region

In this study, we determined the sub region based observations of MCZ. The results of the determination of the partition can be shown in Fig. 1.

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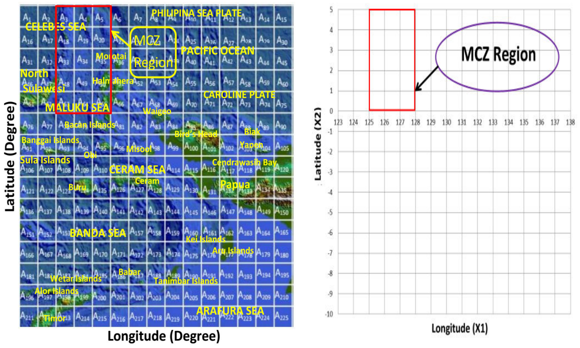


(a) Location of MCZ Region (b) Location of MCZ Region in R^2

Fig. 1 Location of MCZ Region

Based on Fig. 1 (a) shows the location MCZ. Locations in the MC zone is at 0^0-5^0 (Latitude) and 125^0 - 128^0. (Longitude) Then the results on a map that has been partitioned will be shown in field 2 (Fig. 1 (b)). Fig. 1 (b) can be determined based on the set of regions for each partition in the sub-region MCZ. Determination of the set of the partitions on the MCZ aims to avoid repeating the calculation of an event happening earthquake on a different partition regions. In the MCZ there are 15 regions partitions the result set so that there are 15 regions, namely:

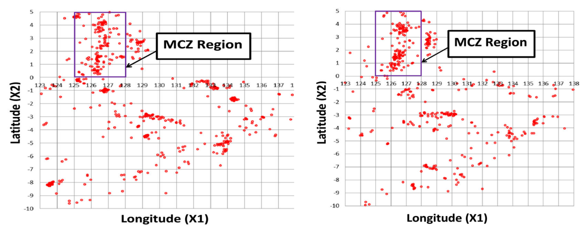
$$B_{2+k} = \{(x_1, x_2) | \ 124 + k \leq x_1 < 125 + k; \ 4 < x_2 \leq 5\}, \quad k = 1, 2, 3;$$

$$B_{17+k} = \{(x_1, x_2) | \ 124 + k \leq x_1 < 125 + k; \ 3 < x_2 \leq 4\}, \quad k = 1, 2, 3;$$

$$B_{32+k} = \{(x_1, x_2) | \ 124 + k \leq x_1 < 125 + k; \ 2 < x_2 \leq 3\}, \quad k = 1, 2, 3;$$

$$B_{47+k} = \{(x_1, x_2) | \ 124 + k \leq x_1 < 125 + k; \ 1 < x_2 \leq 2\}, \quad k = 1, 2, 3;$$

$$B_{62+k} = \{(x_1, x_2) | \ 124 + k \leq x_1 < 125 + k; \ 0 \leq x_2 \leq 1\}, \quad k = 1, 2, 3$$



(a) Distribution of earthquake in 2012 (b) Distribution of earthquake in 2013

Fig. 2 Distribution of Earthquake at MCZ (2012-2013)

A. Calculation Number of Earthquake Occurrence

The calculation of the number of occurrences of the earthquake will be performed on the MCZ partition per year for the period 1964 - 2013 will be shown the distribution Previous earthquakes in MCZ per year for the period 1964 – 2013. In Fig. 2 will only be shown the distribution of events MCZ earthquake per year for the period 2012-2013.

B. Boxplot of Partition Region of MCZ

We will show boxplot of all partition in MCZ with Fig. 3.

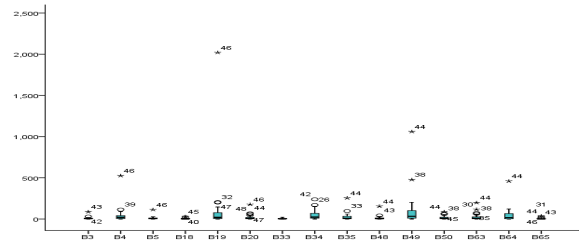


Fig. 3 Boxplot of all Partition of MCZ Region

In Fig. 3, there are some extreme values and outliers in the boxplot for several regions partitions. This is because in a certain year frequency of occurrence of earthquakes is very high compared with the frequency of earthquakes in other partitions in some areas. The other side, in Fig. 4 is seen that the boxplot partition of B_3-B_5, B_{18}-B_{20}, B_{33}-B_{35}, B_{48}-B_{50}, and B_{63}-B_{65} have data and extreme outliers.

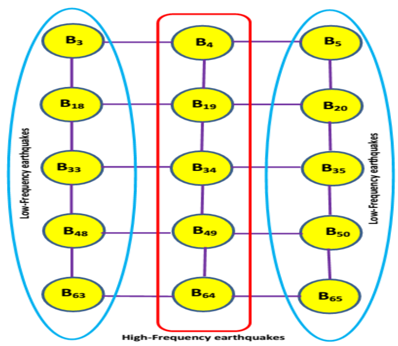


Fig. 4 Grouping Diagram Partitioning Based on Boxplot Results in MCZ

Based on Fig. 3 is seen that the partition B4 has a higher variation of B_3 and B_5, B_{19} has a higher variation of the B_{18} and B_{20}, B_{34} has a higher variation of the B_{33} and B_{35}, B_{49} has a higher variation of the B_{48} and B_{50}, and B_{64} have variation is higher than B_{63} and B_{65}. In addition to having a high variation, the partition B_4, B_{19}, B_{34}, B_{49} and B_{64} also have a minimum and a maximum value higher than the partition in the left and right. This shows that the number of earthquakes in the area partition B_4, B_{19}, B_{34}, B_{49} and B_{64} tend to be higher compared with the partition in the left and right so that the partition is a concern, as shown in Fig. 4.

C. Histogram of Partition Region MCZ

The following shows the number of earthquake occurrence histogram for each region partition B_3-B_5, B_{18}, B_{20}, B_{33}-B_{35}, B_{48}-B_{50}, and B_{63}-B_{65} and its P-Value as shown in Fig. 5.

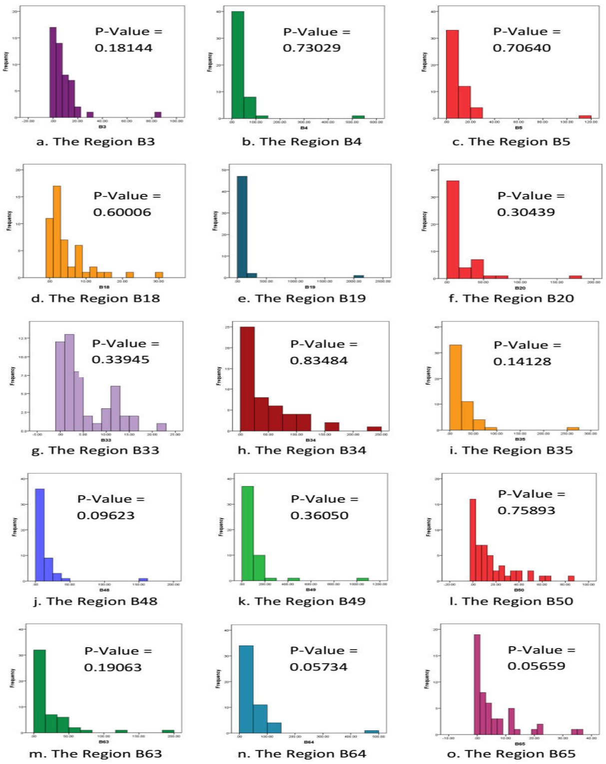


Fig. 5 Histogram of Partition Regions B_3-B_5, B_{18}-B_{20}, B_{33}-B_{35}, B_{48}-B_{50} and B_{63}-B_{65} in MCZ

Based on the histogram in Figs. 5 (a)-(o) suspected partition each region B_3-B_5, B_{18}-B_{20}, B_{33}-B_{35}, B_{48}-B_{50} and B_{63}-B_{65} geometric distribution. Furthermore, the distribution will be determined the type of each partition is using the Kolmogorov-Smirnov test. Then by using the Kolmogorov-Smirnov test results show that 1 partition area that B_{19} does not follow one of distribution while the other 14 regions partitions the B_3-B_5, B_{18}, B_{20}, B_{33}-B_{35}, B_{48}-B_{50}, and B_{63}-B_{65} follow the geometric distribution with α = 0.05, P-Value (Fig. 5), and the parameters as shown in Table I.

TABLE I
TYPE OF DISTRIBUTION OF 15 PARTITION REGIONS IN MCZ

Partition Regions	*Parameter (p)*	*Partition Regions*	*Parameter (p)*
B_3	0.04163	B_{35}	0.02806
B_4	0.01801	B_{48}	0.05682
B_5	0.03828	B_{49}	0.00920
B_{18}	0.08052	B_{50}	0.01884
B_{19}	-	B_{63}	0.03318
B_{20}	0.04098	B_{64}	0.01846
B_{33}	0.08333	B_{65}	0.09690
B_{34}	0.01466		

D. Means of Number Earthquakes on the MCZ

This section will test whether the average number of earthquakes per partition all the same or are there two or more that are not the same for the area per partition B_3-B_5, B_{18}-B_{20}, B_{33}-B_{35}, B_{48}-B_{50}, and B_{63}-B_{65}. Specified hypothesis statement H_0: $\mu_1 = \mu_2 = ... = \mu_r$, all the means are the same H_1: two or more means are different from the others

Further processed by using Excel software obtained ANOVA table is as shown in Table II.

TABLE II
ANOVA TABLE OF EARTHQUAKE OCCURRENCE OF ALL PARTITION IN MCZ REGION

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	482529.9	14	34466.42	4.12	0.00000059	1.705
Within Groups	6154007	735	8372.798			
Total	6636537	749				

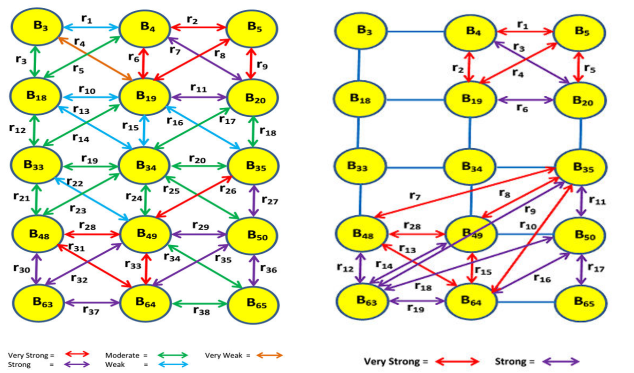
Since the P-value <α with 1% ≤α≤10% then H_0 is rejected. It can be concluded that the mean number of occurrences of earthquakes in 15 regions there are not the same partition. Based on the results of follow-up was conducted to test the mean of two or more regions partitions using one-way ANOVA obtained some results which indicate that there are two or more partitions are not the same as using α = 0.05 level. Some examples of the test can be shown by Table III.

TABLE III
P-VALUE OF SOME PARTITION REGION USING ONE-WAY ANOVA

Partitions	P-Value	Partitions	P-Value
B_4B_5	0.019	B_3-B_5	0.004
$B_{33}B_{63}$	0.001	B_{18}-B_{20}	0.038
B_3B_{18}	0.046	B_3-B_4	0.013
$B_{63}B_{65}$	0.002	B_5-B_{18}	0.035

E. Correlation between Two Partitions Region in MCZ

Here is shown the correlation between the regions closest partition in accordance with the order of the partitions on the MCZ, as shown in Fig. 6 (a).



(a) Correlation Nearby Areas

(b) Correlation Category Strong - Very Strong

Fig. 6 Diagram of Correlation Nearby Areas and category Strong - Very Strong of all Partition in MCZ Region

Fig. 6 (a) shows that there are very weak, weak, moderate, strong, and very strong correlations. We will focus at strong and very strong correlation and we divided in two groups. The first group on the island Talaud and the surrounding area which includes the partition B_4, B_5, B_{19}, and B_{20}. While the second group on the part of the island of Halmahera and butt end of Sulawesi north of the partition that includes B_{35}, B_{48}, B_{49}, B_{50}, B_{63}, B_{64}, and B_{65}. Furthermore, the value of correlation coefficient r_1 - r_{38} in Fig. 6 (a) can be show in detail as shown in Table IV.

TABLE IV
THE CORRELATION BETWEEN 2 PARTITIONS IN MCZ REGION

Correlation Coefficients	Value of Correlation Coefficients	Correlation Coefficients	Value of Correlation Coefficients
r_1	0.22	r_{20}	0.64
r_2	0.95	r_{21}	0.44
r_3	0.48	r_{22}	0.37
r_4	0.19	r_{23}	0.52
r_5	0.42	r_{24}	0.52
r_6	0.97	r_{25}	0.59
r_7	0.89	r_{26}	0.90
r_8	0.94	r_{27}	0.78
r_9	0.92	r_{28}	0.91
r_{10}	0.29	r_{29}	0.77
r_{11}	0.85	r_{30}	0.82
r_{12}	0.58	r_{31}	0.95
r_{13}	0.39	r_{32}	0.83
r_{14}	0.51	r_{33}	0.92
r_{15}	0.25	r_{34}	0.58
r_{16}	0.22	r_{35}	0.78
r_{17}	0.48	r_{36}	0.79
r_{18}	0.53	r_{37}	0.88
r_{19}	0.54	r_{38}	0.68

Table IV shows that the correlation between the partitions on large sequential MCZ correlations varied that there is a weak, moderate, strong and very strong. In other words, each local partition in MCZ Region has a relationship with each other with a correlation coefficient varies. Correlation of 2 partitions in MCZ region for strong and very strong category as a whole can be demonstrated by Fig. 8. Fig. 6 (b) shows that there are a strong and a very strong correlation in two group regions of partition. The first group on the island Talaud and the surrounding area which includes the partition B_4, B_5, B_{19}, and B_{20}. While the second group on the part of the island of Halmahera and but end of Sulawesi north of the partition that includes B_{35}, B_{48}, B_{49}, B_{50}, B_{63}, B_{64}, and B_{65}. Furthermore, the value of correlation coefficient $r_1 – r_{19}$ in Fig. 6 (b) can be demonstrated in detail by using Table V.

TABLE V
THE CORRELATION BETWEEN TWO-PARTITION IN MCZ REGION BASED ON STRONG-VERY STRONG

Correlation Coefficients	Value of Correlation Coefficients	Correlation Coefficients	Value of Correlation Coefficients
r_1	0.95	r_{11}	0.78
r_2	0.97	r_{12}	0.82
r_3	0.89	r_{13}	0.95
r_4	0.94	r_{14}	0.83
r_5	0.92	r_{15}	0.92
r_6	0.89	r_{16}	0.78
r_7	0.92	r_{17}	0.79
r_8	0.90	r_{18}	0.71
r_9	0.79	r_{19}	0.88
r_{10}	0.93		

III. CONCLUSION

Based on the results and discussion we can conclude several things, among others, that the central part of the partition has the tendency of many earthquakes are higher when compared with the left and right partitions. Then some areas have a tendency to partition a close relationship with one another. In MCZ, there are a strong and a very strong correlation in two group region of partition. The first group on the island Talaud and the surrounding and the second group on the part of the island of Halmahera and butt end of Sulawesi north. In addition, the mean occurrence of earthquakes each year from 1964 to 2013 is not the same. The type of distribution of all partition in MCZ region is geometric distribution except partition region B_{19}. Thus for areas that need attention is the maximum of the local and central government. These results can be used as a reference for the North Molluca and North Sulawesi provincial government to make the draft spatial by considering aspects of disaster, early education about earthquakes, disasters and dangers and prepare evacuation route.

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