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Spatial Autocorrelation of Earthquake Magnitudes in Tripa Fault, Aceh Province, Indonesia

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Abstract. The position of Aceh coincides with the fault zone along the Bukit Barisan called Sumatran Fault. The Tripa Fault is marked by the mountainous area and the trajectory of the Kuala Tripa and Meureubo Rivers along 180 km. Tripa faults are categorized as active faults indicated by the occurrence of several destructive earthquakes in the region. One effort that can be done to reduce the negative impacts caused by the earthquake disaster is to make predictions by mapping the occurrence of earthquakes. The purpose of this study was to determine the relationship between the incidence of earthquakes in the Tripa Fault region of Aceh Province. The data used in this study are earthquake occurrence parameters in the Tripa Fault region from 1990-2017. The results obtained show that there is a global spatial autocorrelation between the magnitude of the occurrence of earthquakes in the region around the Tripa Fault in Aceh Province with several magnitudes of earthquake events having local spatial autocorrelation.

1. Introduction
The Sumatra fault stretching from Aceh to the Sunda Strait. One part of the Sumatra Fault is a Tripa fault. Tripa fault is categorized as active fault. Tripa Fault is characterized by mountainous areas and trajectories of large river along the 180 km. The big river is Kuala Tripa River and Meureubo River. Some earthquakes caused by Tripa Fault movements have considerable and destructive power. Some earthquakes caused by Tripa fault movements have considerable and destructive power. At the center of the segment precisely in the Gayo Lues region in 1990 an earthquake occurred with magnitude 6.1.

Efforts in disaster management (disaster mitigation) to minimize losses caused by earthquakes can be done by mapping in the form of maps prone to earthquake disasters [1]. A spatial earthquake research in Aceh province years 1921-2014 was undertaken by Affan in 2016, the purpose of the research is to detect groups and look for spatial patterns during the period 1921-2014 using GIS. The methods used are Average Nearest Neighbor, Moran Global Index, The Getis-Ord General G, Anselin Local Moran Index, Getis-Ord Gi* and Kernel Density Estimation. One result of the study shows that earthquakes are grouped from the southwest to the northern part of the province [2].
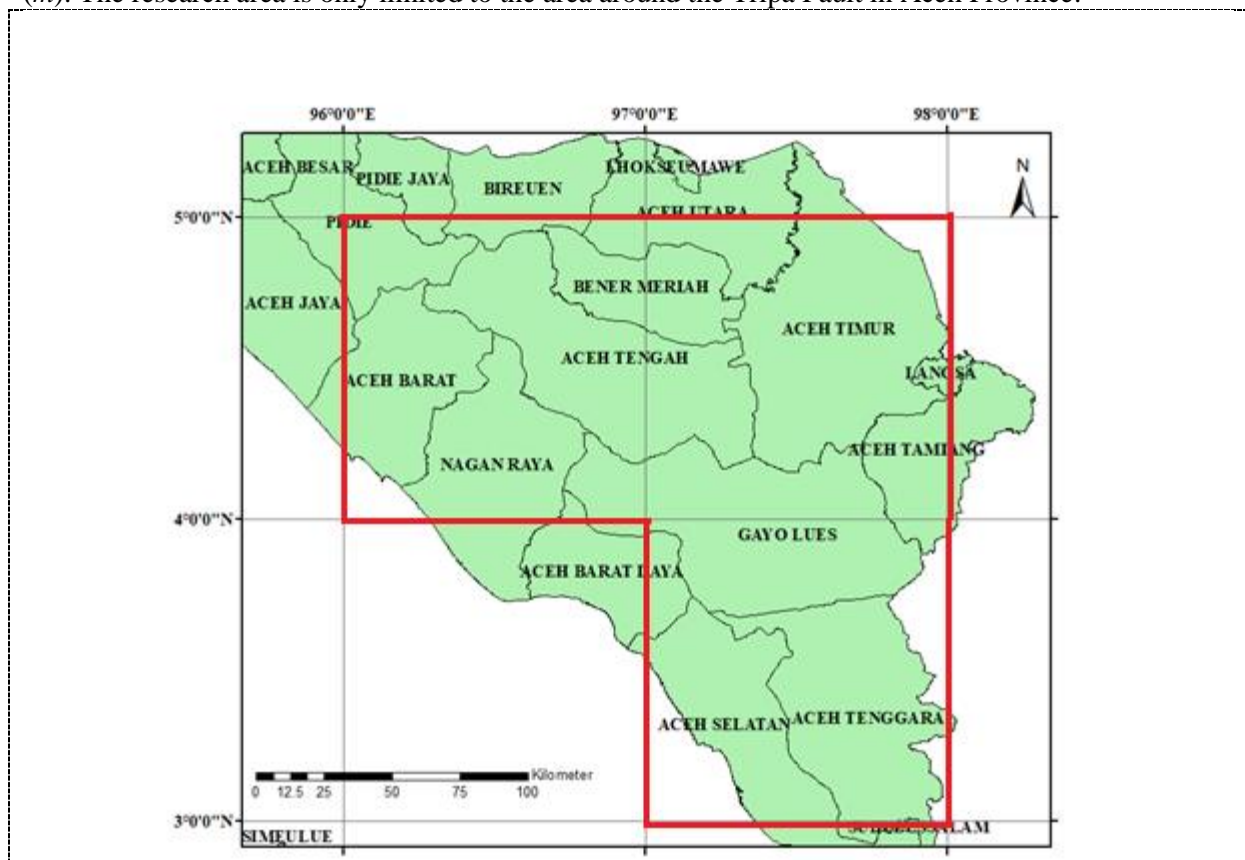
The background above is the reason why the author performs data analysis to see the magnitude of the occurrence of earthquakes in relation to the magnitude of other earthquake events in an area and see the return period of earthquakes in the Aceh region, especially around the Tripa fault. This research is expected to be able to provide disaster information in increasing public awareness, especially those living in the area around the Tripa Fault in Aceh Province.

2. Data and Methods

2.1. Data

The data used in this study is secondary data, namely the occurrence of earthquakes in the Tripa Fault region of the Province of Aceh with variables of longitude, latitude and earthquake magnitude. Earthquake occurrence data used began from January 1990 to December 2017. The total occurrence of earthquakes that occurred in that time span was 598 events. The magnitude of the earthquake occurrence data starts from $M = 1.8$ to $M = 6.7$. Because the Meteorology, Climatology and Geophysics Agency (BMKG) only has an earthquake data repository from 2009, data from 1990 to 2008 were obtained from the United States Geological Survey (USGS) repository. The variables used in this study are longitude points (x), latitude points (y) and earthquake strength variables denoted by (m). The research area is only limited to the area around the Tripa Fault in Aceh Province.

Figure 1. The research area.

2.2. Data Analysis Methods

Data analysis begins by combining data from both sources into one dataset. Then the time of the earthquake occurrence from USGS was converted to Waktu Indonesia Barat (WIB) and the magnitude of Mw so that the data from the USGS and BMKG had the same type of time and magnitude. Then the data is selected based on the magnitude of $Mw \geq 3$ so that 322 data remain. Identification of the pattern of earthquake magnitude distribution is done by spatial analysis, namely the global and local spatial autocorrelation test using *R studio 1.0.143* dan *ArcMap 10.4.1*.

Spatial object geometry information is entered into several forms, namely points, lines and polygons. Spatial analysis of earthquake magnitude uses point objects. Point data consists of a collection of event

location points with spatial coordinates x (longitude) and y (latitude point) in an area [3]. The Moran index can be used to see the relation of point objects and distribution patterns from point data. The spatial autocorrelation test was tested in two ways, namely global testing and local testing [4].

The global Moran index can be calculated using the following formula:

$$I = \frac{n}{S_0} \cdot \frac{\sum_i^n \sum_j^n w_{i,j}(y_i - \bar{y})(y_j - \bar{y})}{\sum_i^n (y_i - \bar{y})^2} \tag{2.1}$$

where

y_i = observation y at the i location.
y_j = observation y at the j location.
$\bar{y}$ = average value of y in all observations.
n = total number of locations.
w = spatial weighting matrix.
S_0 = factor scale or the sum of all elements of the W value.
i = longitude.
j = latitude [5].

The Moran Index is used to test spatial dependency or autocorrelation between observations or locations. The hypothesis used is:
$H_0 : I = 0$ (there is no spatial autocorrelation)
$H_a : I \neq 0$ (there is spatial autocorrelation)
Decision making rejects H_0 if $p-value \leq \alpha$, with a value of $\alpha = 0,05$ [6].

After testing the spatial autocorrelation globally, it is necessary to test the validity of the results using a local spatial autocorrelation test. The local spatial autocorrelation test was carried out with the Local Indicators of Spatial Association (LISA). LISA is an exploratory analysis method for spatial data that is able to detect spatial relationships at the local level and their influence globally. LISA can be calculated by the equation (2.2).

$$I_i = \frac{(x_i - \bar{x})}{\sqrt{\sum_{i=1}^n \frac{(x_i - \bar{x})^2}{n-1}}} \sum_j w_{ij} \frac{(x_j - \bar{x})}{\sqrt{\sum_{j=1}^n \frac{(x_j - \bar{x})^2}{n-1}}} \tag{2.2}$$

Where $i = 1, 2, ..., n$ with n is the number of observation locations, w_{ij} is an element of the spatial weighting matrix that has been standardized in rows, $\bar{x}$ is the average value of x_i, x_i is the value of observation at the i location and x_j is the value of observation at the j location. The hypothesis used for the LISA test is:
$H_0: I_i = 0$ (there is no spatial autocorrelation at the i location)
$H_1: I_i \neq 0$ (there is spatial autocorrelation at the i location)

The test statistics used in the LISA test are the same as those on the Moran's index. However, calculation of variance from LISA is done by equation (2.3).

$$\text{var}(I) = \frac{w_i^{(2)}(n - b_2)}{n-1} + 2w_{i(kh)} \frac{(b_2 - n)}{(n-1)(n-2)} - \frac{w_i^2}{(n-1)^2} \tag{2.3}$$

Where $w_i^{(2)} = \sum_{j \neq i} w_{ij}^2$, $w_{i(kh)} = \sum_{k \neq i} \sum_{h \neq i} w_{ik} w_{ih}$, $w_i^2 = \left(\sum_{j \neq i} w_{ij}\right)^2$, $b_2 = \frac{m_4}{m_2^2}$, $m_2 = \sum_i z_i^2 / n$, $m_4 = \sum_i z_i^4 / n$, and z_i = standardized observation values. Decision making is done if $p\text{-}value \leq \alpha$ (0.05) then reject H_0, which means there is spatial autocorrelation at the i location [7].

The Moran index coefficient ranges between -1 and +1. If the Moran index is negative it indicates that the data distribution pattern is spreading. Whereas if the autocorrelation is positive, the data distribution pattern is in groups [8].

The weighting matrix used in this study uses distance weights. Distance weight is an inverse distance matrix formed based on Euclidean distance. If given two locations with coordinates (x_i, y_i) and (x_j, y_j), then the Euclidean distance from that location is:

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{2.4}$$

The elements of distance weight matrix are defined as follows.

$$W_{ij}^{(\ell)} = \begin{cases} \dfrac{\dfrac{1}{1 + d_{ij}^{(\ell)}}}{\sum_{j=1}^{n} \dfrac{1}{1 + d_{ij}^{(\ell)}}}, & j \text{ is neighbor } i \text{ at the } \ell \text{ lag} \\ 0, & others \end{cases}$$

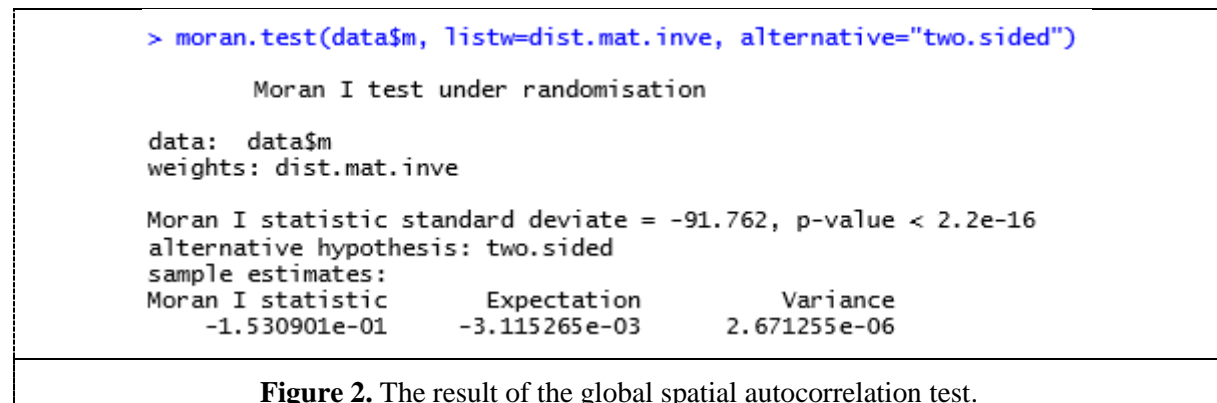With d_{ij} is the Euclidean distance and W_{ij} is the weighting matrix element [9].

3. Result and Discussion

3.1. Global spatial autocorrelation test

The global spatial autocorrelation test is conducted to determine the relationship between the magnitude of the earthquake occurrence in the region around the Tripa Fault in Aceh Province. The global spatial autocorrelation test uses the following hypothesis:

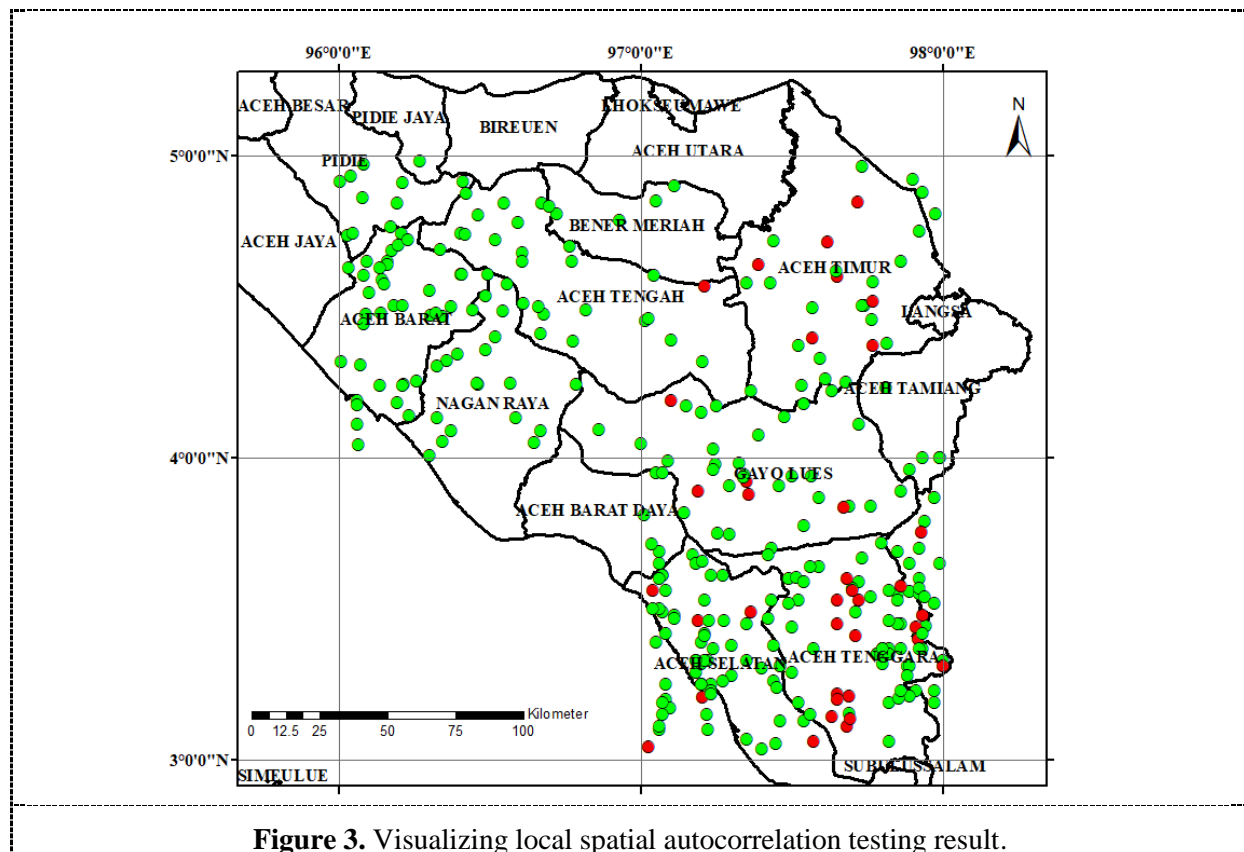$H_0 : I = 0$ (there is no spatial autocorrelation)

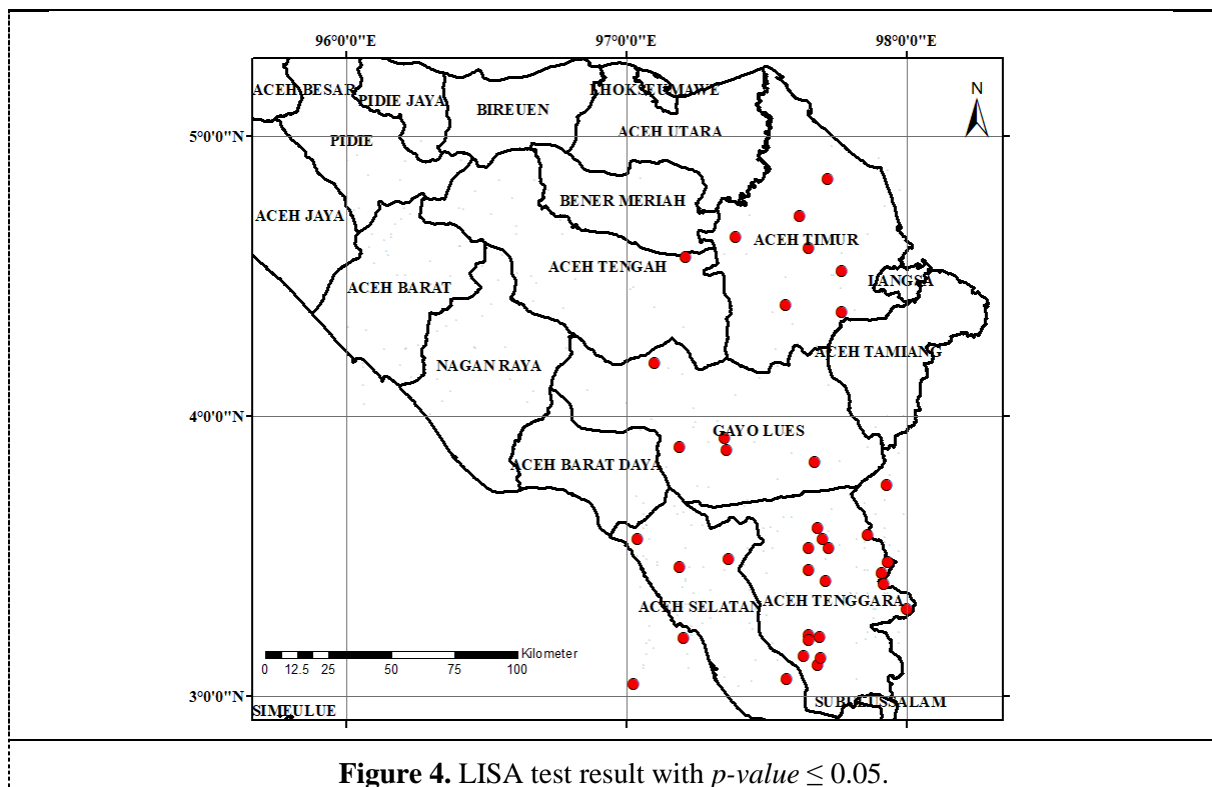$H_a : I \neq 0$ (there is spatial autocorrelation)

```
> moran.test(data$m, listw=dist.mat.inve, alternative="two.sided")

        Moran I test under randomisation

data:  data$m
weights: dist.mat.inve

Moran I statistic standard deviate = -91.762, p-value < 2.2e-16
alternative hypothesis: two.sided
sample estimates:
Moran I statistic       Expectation            Variance
    -1.530901e-01      -3.115265e-03        2.671255e-06
```

Figure 2. The result of the global spatial autocorrelation test.

Based on the results of testing the global spatial autocorrelation in the area around the Tripa Fault (Figure 2), the resulting p-value is $2,2 \times 10^{-16}$. Because *p-value* $< \alpha$ (0,05) then the decision rejects the null hypothesis. The decision shows that there is a spatial relationship between the magnitude of earthquake events for all study areas located around the Tripa Fault of the Province of Aceh. Because the Moran index value obtained is -0,153, then there is a spatial relationship between magnitudes which is negative in the Tripa Fault in Aceh Province, so that it can be concluded that the occurrence of earthquakes adjacent to the area around the Tripa Fault in Aceh Province has a different magnitude. In addition, the negative Moran index also identifies that the magnitude of earthquake events of the same size are spread or not adjacent.

3.2. Local indicators partial autocorrelation test

As the validity of the global spatial autocorrelation test which states that there is a relationship between the magnitude of the occurrence of earthquakes, the spatial autocorrelation test is carried out locally. This test is carried out to see which earthquake points are affected by other earthquake points. Testing is done using the LISA Test. Visually the results are as shown in Figure 3.
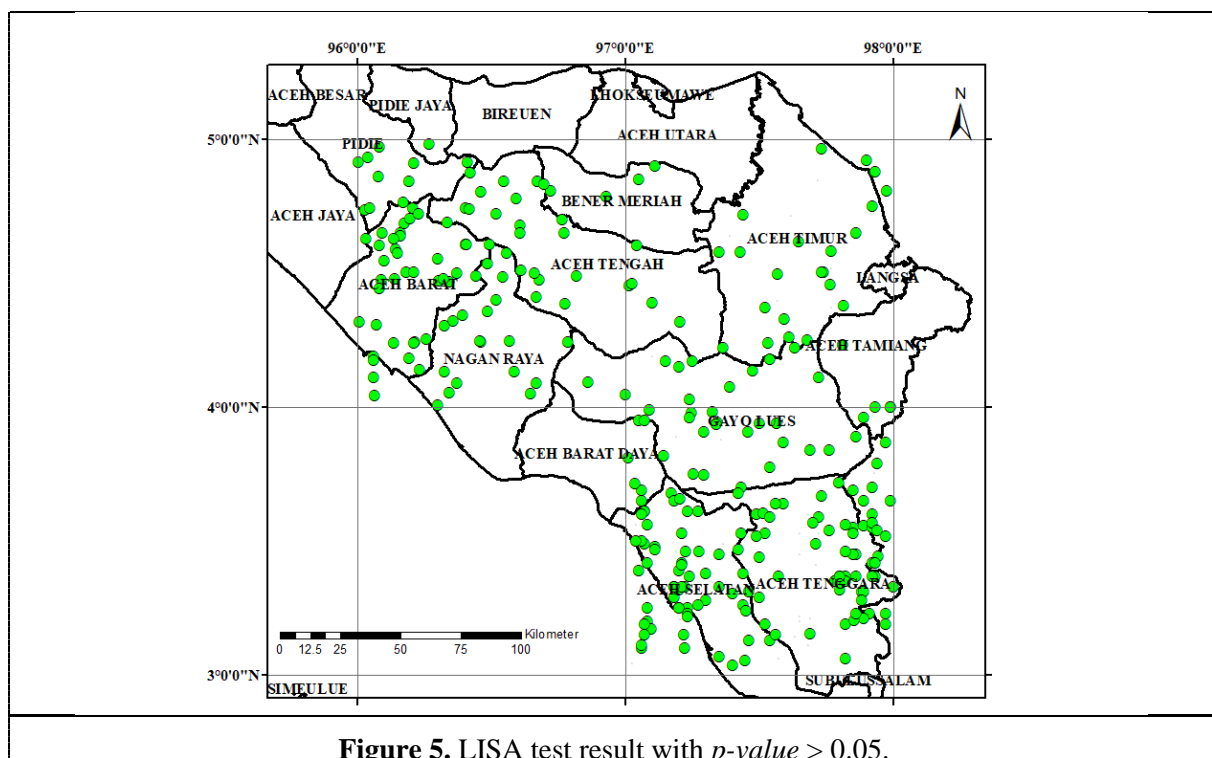
Figure 3. Visualizing local spatial autocorrelation testing result.

Locally, as much as 37 earthquakes magnitude have *p-value* less than α = 0.05. 37 magnitudes have local spatial autocorrelation. This means that from 322 magnitudes earthquake occurrence around the Tripa fault with magnitude ≥ 3 there are 37 magnitudes earthquake occurrence that are really affected by the magnitude of adjacent earthquake. Because the Local Moran index of 37 earthquake magnitudes is positive, then the earthquakes have the similar magnitude as its neighbors.

Figure 4. LISA test result with *p-value* ≤ 0.05.

Based on Figure 4. it can be seen that the earthquake magnitude points marked in red have *p-value* ≤ 0.05 or have spatial autocorrelation, which means that the occurrence of earthquakes with the same magnitude is in an adjacent location, while the occurrence of earthquakes with different magnitudes is in a spread location.

Figure 5. LISA test result with *p-value* > 0.05.

Based on Figure 5. it can be seen that the magnitude of the earthquake marked with a green dot have *p-value* > 0.05 or there is no spatial autocorrelation, which means that the occurrence of earthquakes with the same magnitude is at a spread location, while earthquakes with different magnitudes are in adjacent locations.

4. Conclusions

Based on the results, the conclusions this research are: there is a relationship between the earthquake magnitudes globally in the Tripa fault region, the negative Global Moran index indicates that any earthquake occurrence of an adjacent area around Tripa Fault in the Aceh Province has a difference magnitude, in other words the similar earthquake magnitudes have spread distribution or not close together. Locally, 37 earthquake magnitudes are actually affected by the magnitude of the adjacent earthquake magnitude and have a magnitude that tends to be similar to the neighbors.

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