

# Geovisualization Using Hexagonal Tessellation for Spatiotemporal Earthquake Data Analysis in Indonesia

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**Abstract.** Geovisualization process is the key in map design to extract information from geospatial data set especially on big data. The use of point feature in the geovisualization process of earthquake spatial data in Indonesia caused some problems such as overlapping between symbols, complications due to the large amount of data, and uneven spatial distribution. This research aims to create geovisualization of earthquake spatial data in Indonesia using hexagonal tessellation method, analyze earthquake map in Indonesia based on geovisualization using hexagonal tessellation and interpret earthquake map in Indonesia based on geovisualization using hexagonal tessellation spatiotemporally. The method used in this research is geovisualization of earthquake spatial data in Indonesia using hexagonal tessellation. This research use earthquake epicenter density analysis to discover and illustrate the spatial phenomena pattern of the earthquake epicenter into more easily understood information. The density analysis includes distance matrix analysis to examine the visualization result and proximity analysis to know the proximity of earthquake density represented by centroid hexagon point with the tectonic plate fault line. The result of this research is earthquake map in Indonesia based on geovisualization using hexagonal tessellation in Indonesia 2010 to 2015. The result of this research shows that the map design of earthquake geospatial information using hexagonal tessellation geovisualization method can show the density distribution of earthquake point spatiotemporally. The earthquake epicenter density analysis in Indonesia based on geovisualization using hexagonal tessellation showed that the hexagon centroid point with high density attribute earthquake data of all magnitude classes tended to have a closer distance to the tectonic plate fault lines spatially.

**Keywords:** Geovisualization · Tessellation · Hexagonal · Earthquake

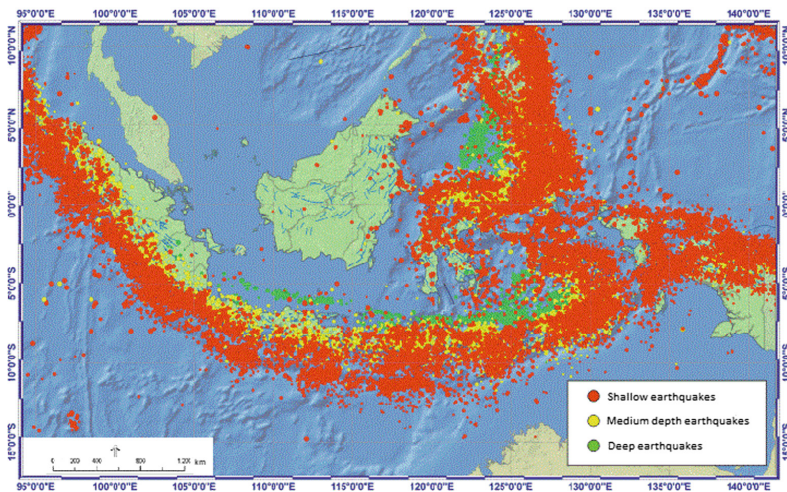
## 1 Introduction

The spatial data is related to the spatial analysis aimed to obtain new information that can derive from big data. The important aspect of the spatial analysis is the representation or visualization of data [6]. Visualization techniques are needed to produce an effective and easy-to-read map. Visualization of the spatial data in large quantities,

especially for a point feature has its own problems in the process of visualization such as overlapping among symbols, many complications because of the amount of data, and the uneven spatial distribution [14].

One of the methods to visualize point-based spatial data is using tessellation. Tessellation method can visualize spatial data points using basic geometric shape. Geometries that can be used is square, hexagon, triangle, or other geometry shapes. Hexagonal shape in cartography simplifies the process of changing the cell size when the scale of the map was changed without reducing the level of readability on the map [14]. Meanwhile, using a square shape causes the reader uncomfortable and difficult to explaining the spatial patterns [4]. Hexagon has a higher representational accuracy and when analyzed statistically, the hexagon has a direct border with six neighbors, instead of four neighbors like the square shape [13]. Cell size variation that can be adjustable in a hexagon shape allows customization of cell sizes appropriate for different scale levels and have the potential to resolve Modifiable Areal Unit Problem [10].

Examples of point-based spatial data that has a large amount and problems in the representation, as mentioned above, is the earthquake spatial data in Indonesia issued by the Meteorological, Climatology and Geophysics Agency showed on Fig. 1. Indonesia is located on the active tectonic plates fault, annually earthquake-ravaged from small scale to large scale. Spatial data generated would continue to increase so that the visualization process should be appropriate in order to avoid a decrease in the level of readability when presented in map form. Visualization of earthquake data in Indonesia still has problems that commonly occur in the representation of spatial data point.



**Fig. 1.** Indonesia earthquake map 1973–2010 by meteorological, climatology and geophysics agency (BMKG)

The problem of earthquake spatial data visualization in Indonesia causes the difficulty of epicenter spatial distribution analysis. The map which exists today

represented the earthquakes in the point-based spatial data inflicts many points of earthquake events overlap one another. Its effect on the information of earthquake events distribution cannot be analyzed temporally well. In addition, seismic data attributes such as earthquake magnitude and depth are not represented their distribution on the map with the result is difficult to analyze spatially and temporally.

The occurrence of earthquakes is closely related to the movement of tectonic plates. Earthquakes often occur in regions that are close with tectonic faults called earthquake zone [7]. However, the visualization in the form of a point cannot describe the spatial and temporal how the actual relationship between the earthquake epicenters point with a fault line. Therefore, this study aimed to examine the earthquake spatial data visualization in Indonesia using hexagonal tessellation method and then used as a model of the earthquake epicenter dot density analysis in spatial-temporal distance to determine how the relationship with the fault lines of tectonic plates.

## 2 Collecting and Processing Earthquake Spatial Data

Earthquake spatial data in Indonesia is obtained from the Agency of Meteorology and Geophysics through the official website. The earthquake epicenter data is downloaded based on the time range from 2010 to 2015. The territorial boundaries studied are 6° LU–11° LS and 94° BT–142° BT. The downloaded data is in text format so it is necessary to convert into a table format using Micosoft Excel numeric software. Table data contains coordinates, earthquake depth, magnitude earthquake, and earthquake event time attributes. This research only uses coordinates attributes and magnitude of the earthquake.

Data processing begins by converting table data into point spatial data using Quantum GIS software. Based on the coordinate information in the attribute table, the earthquake epicenter point obtained and then stored in shapefile spatial data format. The earthquake spatial data are classified according to their magnitudes. The classification of earthquake magnitude used is less than 4.0 RS, 4.0–5.0 RS, and more than 5.0 RS.

Figure 2 showed that the earthquake spatial data presented using the point feature encountered many problems in reading, analysis, and interpretation. The number of

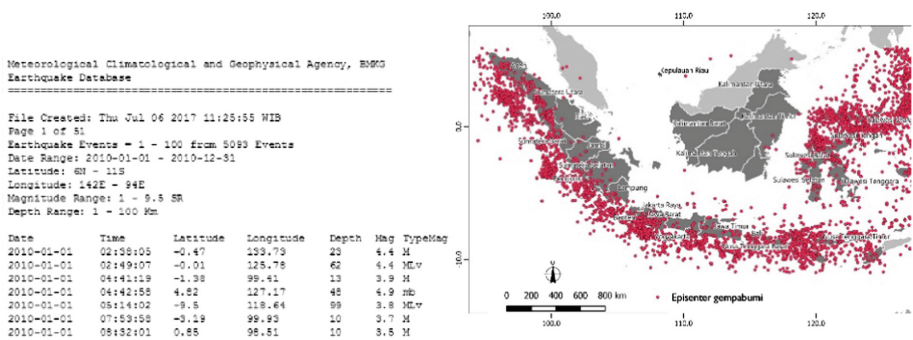
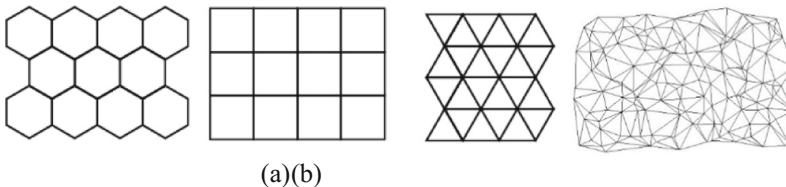


Fig. 2. Converting earthquake table data to earthquake spatial data

earthquake epicenter points with an average of 5181 epicenter annually from 2010 to 2015 in the territory of Indonesia resulted visualization using points caused covering each other at the frequent earthquake epicenter. It reduces the level of information understanding that can be extracted from the data so that its usage is not maximal and cannot be analyzed further.

### 3 Geovisualization Using Hexagonal Tessellation

Tessellation is a process of preparing a data representation by creating partitions using one or more geometric shapes that complement each other without any overlap and gap on each side [15]. Based on the variation of the shape and size, tessellation is divided into two regular tessellation and irregular tessellation [11]. Regular tessellation is a tessellation that uses a uniform shape and size of a geometry cell such as triangles, square, and hexagon to present data. Irregular tessellation is a more complex tessellation which the shape and size of the cell may vary according to its data attributes. Difference between regular and irregular tessellation shown in the Fig. 3.



**Fig. 3.** Regular tessellation (a) and irregular tessellation (b)

The usage of hexagon geometry reduces ambiguity in determining neighbour cells [2]. Hexagon geometry has a shorter perimeter than square with the same area where it can reduce bias due to edge effects [2]. Tessellation for observation has been widely applied to modeling, simulating, and even studying ecosystems. This is because the geometry with the same pattern is an efficient way of surveying, sampling, and experimenting [9]. Hexagonal tessellation can be used to analyze population density in an area for example citizen population in a country [5]. The size of the cells resolution used for hexagonal tessellation mapping on a national scale is 65 km while on the urban scale is 2 km so the map reader can still distinguish the larger pattern without ignoring minor differences [14]. The study area of this research is entire territory of Indonesia that according to Shelton is categorized as national scale so the cells resolution used is 65 km.

#### 3.1 Creating Hexagonal Tessellation Cell

The geovisualization process of point spatial data using the hexagonal tessellation method can be executed after the coordinate system used is similar or equivalent.

Therefore, hexagon cells is created using Web Mercator projection same as the earthquake spatial data. The coordinate boundaries used to generate hexagon cells are  $7.875^{\circ}$  N– $12.194^{\circ}$  LS and  $93.28^{\circ}$  E– $141.387^{\circ}$  east. The benefit of the coordinate boundary is to determine the area to be mapped using hexagonal tessellation where the hexagon cell will cover the entire region as in Fig. 4. Determination of the limit refers to the study area that is all regions of Indonesia that have a history of earthquake occurred from 2010 to 2015.

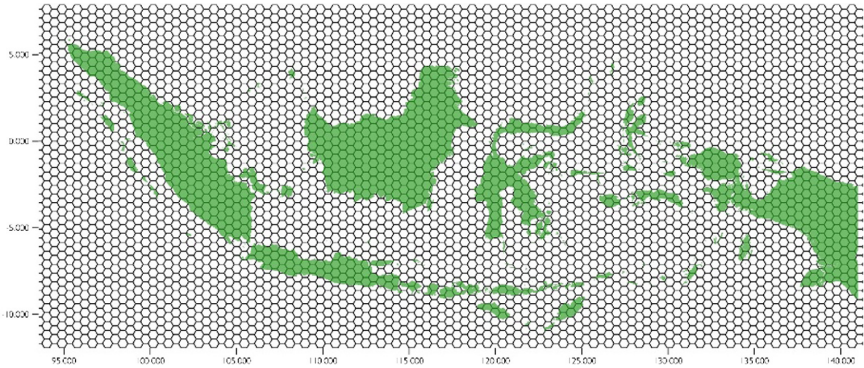


Fig. 4. Creating hexagonal tessellation cell

### 3.2 Hexagonal Tessellation

Geovisualization of hexagonal tessellation executed by covering the epicenter earthquake epicenter data with hexagon cells in each year and each earthquakes classification. The number of points that fall on each hexagon is calculated and stored in the polygon data attribute using analysis tool in QGIS that is counts points in polygon. This research obtained tessellation for each class of earthquake magnitude annually so that there are 18 layers produced and three cumulative maps of the year 2010-2015 in each class of magnitude.

Figure 5 shows the density of earthquakes stored in hexagon cell attributes is classified to symbolized by their density levels. The density information of the

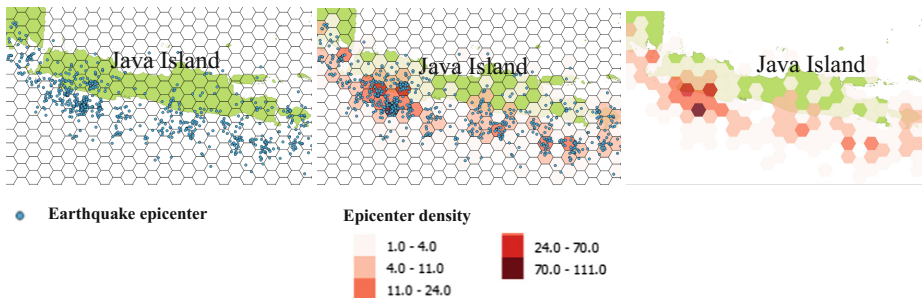


Fig. 5. Hexagonal tessellation process

earthquake is used to assess the relation density of earthquakes with major tectonic plate fault which each hexagon is represented by one centroid point.

## 4 Analysis

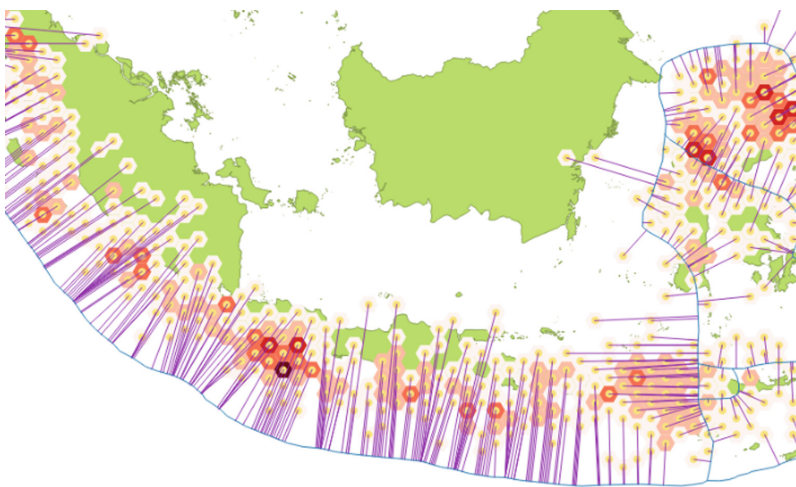
Spatial analysis techniques is various, such as visual observation and mathematics or applied statistics [12]. The advantages of spatial analysis is can be used to explain how the location relationship between the occurrence of a phenomenon to the surrounding phenomenon [8]. The density of earthquakes geospatial data of in Indonesia that have been visualized using hexagonal tessellation method can be analyzed spatially and temporally. The analysis that has been done in this research includes analysis to test the result of hexagonal tessellation and interpretation to know the density distribution or frequency of earthquake occurrence spatiotemporally.

```
d_lyr = QgsVectorLayer('LineString?fied=distance:float', 'dist', 'memory')
QgsMapLayerRegistry.instance().addMapLayer(d_lyr)

p_lyr = QgsMapLayerRegistry.instance().mapLayersByName('Centroid Hex Mag kecil 2010')[0]
l_lyr = QgsMapLayerRegistry.instance().mapLayersByName('Fault line')[0]
d_lyr = QgsMapLayerRegistry.instance().mapLayersByName('dist')[0]
prov = d_lyr.dataProvider()
feats = []
for p in p_lyr.getFeatures():
    minDistPoint = min([l.geometry().closestSegmentWithContext(QgsPoint(p.geometry().asPoint())) for l in l_lyr.getFeatures()])[1]
    feat = QgsFeature()
    feat.setGeometry(QgsGeometry.fromPolyline([QgsPoint(p.geometry().asPoint()), QgsPoint(minDistPoint[0], minDistPoint[1])]))
    feat.setAttributes([feat.geometry().length()])
    feats.append(feat)

prov.addFeatures(feats)
d_lyr.updateExtents()
d_lyr.triggerRepaint()
```

**Fig. 6.** NNjoin code to compute distance between centroid and break line

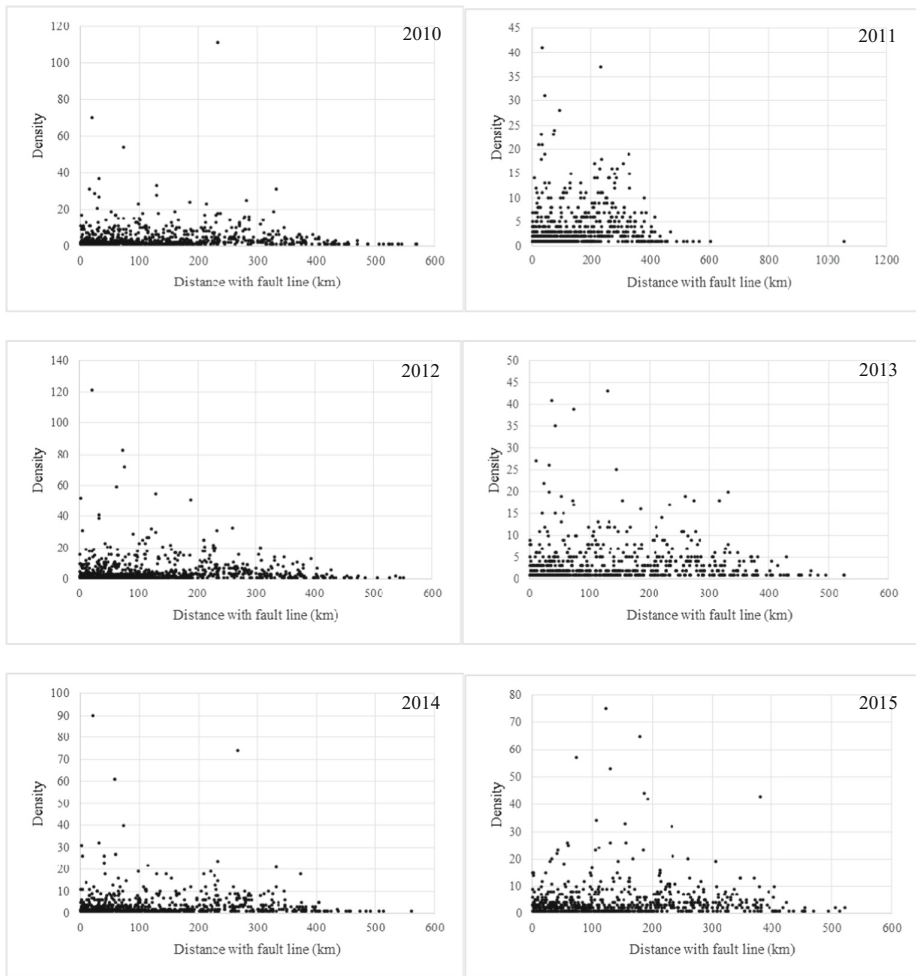


**Fig. 7.** Proximity analysis using hexagon centroid

### 4.1 Proximity Analysis

Proximity analysis is one of spatial analysis by considering the distance of an object with other objects to know their relationship [3]. Proximity analysis was used in this study to assess the density of occurrence of earthquake with major plate fault line. The proximity analysis utilizes an additional NNjoin plugin on QGIS software that enables the calculation of distances between different features which in this study is the hexagon centroid point that contains the attributes of earthquake density with plate fault lines in Indonesia. NNjoin code showed on Fig. 6.

The results of the analysis are then presented in the form of a two-variable scatter plot that is the distance from the fault line and the density level of earthquake



**Fig. 8.** Graph of earthquake magnitude class less than 4.0 RS density with distance to fault line in Indonesia year 2010–2015

occurrence for each class of magnitude and the year of occurrence. The result of proximity analysis is showed on Fig. 7.

The purpose of the proximity analysis is to see how exactly the distance relationship between the two spatial objects is. The distance analysis was carried out using QGIS with additional NNjoin plugins that allowed the calculation of the distance between different features which in this study was the level of earthquake density with plate fault lines. The results of the analysis are then presented in the form of a two-variable scatter plot that is the distance from the fault line and the density level of earthquake occurrence for each magnitude class as well as the year of occurrence.

The distance measuring result of the hexagon centroid with plate fault line is presented on scatter plot which shows the distribution of density of earthquake. Each class of earthquake magnitude has six years of temporal time in from 2010 to 2015.

Scatter plot in Fig. 8 shows the results of spatial data proximity analysis of earthquake data from 2010 to 2015 in Indonesia. Distance between the centroid with fault line is on x axis and density of epicenter is on y axis. The analysis results show spatially the centroid that has high density attribute is closer to plate fault line. This may indicate that the existence of a plate fault line affects the occurrence of earthquakes where the density of the occurrence is higher at closer distance to the fault line (Figs. 9, 10 and 11).

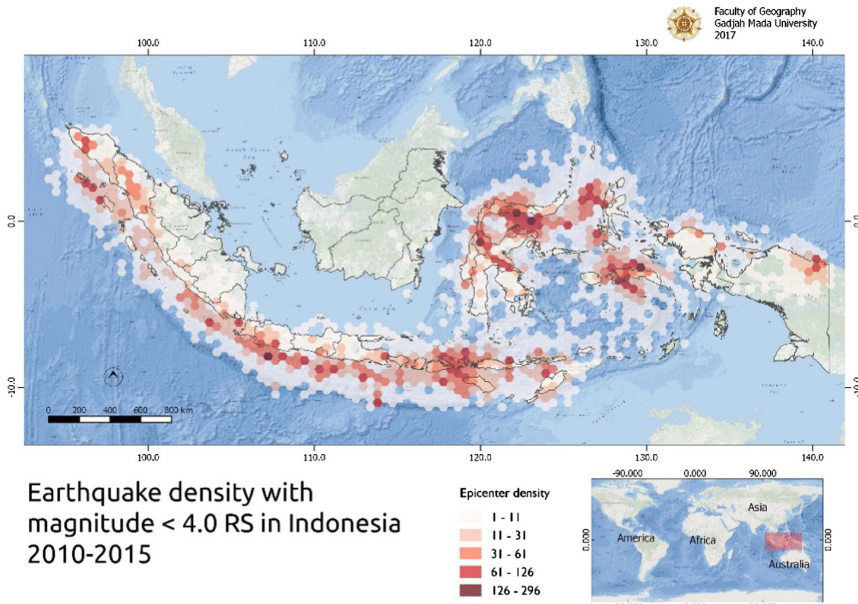
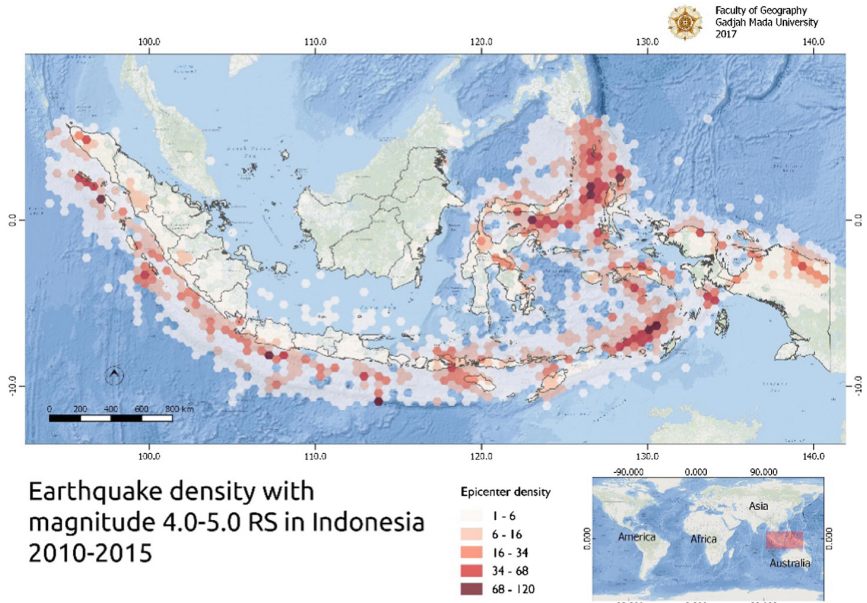
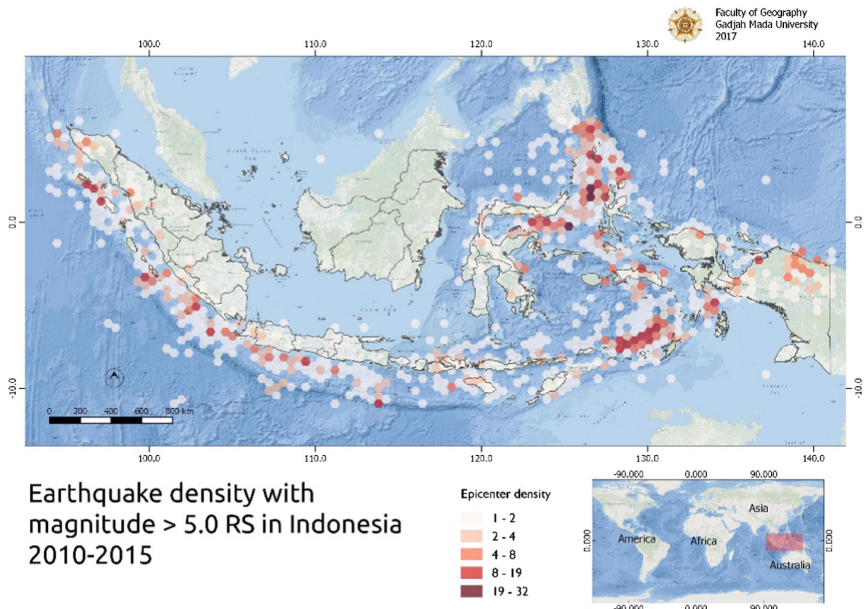


Fig. 9. Earthquake density map with magnitude < 4.0 RS in Indonesia 2010–2015





**Fig. 10.** Earthquake density map with magnitude 4.0–5.0 RS in Indonesia 2010–2015



**Fig. 11.** Earthquake density map with magnitude > 5.0 RS in Indonesia 2010–2015

## 5 Interpretation

Earthquake epicenter shows the existence of tectonic activity in a region because of tectonic earthquake closely related to the existence of plate fault line. The pattern of density level of the earthquake may indicate tectonic activity in an area where in high epicenter density area tectonic activity in the region is classified as intensive. Areas with low epicenter densities indicate that tectonic activity in the region is less intensive.

The results of the interpretation of earthquake maps using hexagonal tessellation geovisualization considering the density of earthquake epicenter shows some areas with intensive tectonic activity such as North Maluku, Sulawesi, southern Java region, southern region of Sumatra, and Papua. One example of significant tectonic earthquake activity in 2010 was in the Mentawai Islands that killed 286 people. In 2015 tectonic activity causes more destructive earthquakes in eastern Indonesia. There are seven recorded events, namely Manggarai Earthquake, Banggai Earthquake, Membramo Raya Earthquake, Sorong Earthquake, Alor Earthquake, West Halmahera Earthquake, and Ambon Earthquake.

## 6 Conclusion

Hexagonal tessellation geovisualization method can show the density distribution of earthquake epicenter point in Indonesia spatiotemporally that may indicate tectonic activity in an area. The proximity analysis shows that spatial centroid hexagon having high density attributes for earthquake data all magnitude classes tend to have a closer distance to major fault lines. Conversely, hexagon centroids that have low density earthquake attributes tend to be farther away from major fault lines. This may indicate that the existence of a plate fault line affects the occurrence of an earthquake where if spatially observed the density of the occurrence of a higher quake at a distance close to the fault line. Interpretation result of earthquake epicenter density maps in Indonesia using hexagonal tessellation indicates that the density level of the earthquake can indicate tectonic activity in an area where in high density epicenter area tectonic activity in the region is classified as intensive.

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