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Study Of Soil Vulnerability in East Java Using Horizontal and Vertical Spectrum Ratio (Hvsr) Method from Ambient Noise Waves

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Abstract. The risk level of an earthquake is determined by the geological condition on the area. East Java has a high level of seismicity. One of the earthquake mitigation efforts is to estimate the dynamic characteristics of ground using microtremors. The purpose of this study was to determine the natural frequency distribution, amplification factor, and seismic vulnerability index. Seismic signals are obtained from stationary and temporal seismograph records from 100 measurement locations installed in the East Java and Madura regions. This study uses the horizontal and vertical spectrum ratio (HVSR) curve analysis method popularized by Nakamura (2000). The results of the study showed that the seismic vulnerability index varied from 0.25 to 54.2. Areas that have a high level of earthquake risk include Bangkalan, Gresik, Jombang, Lumajang, Malang, Mojokerto, Pasuruan, Ponorogo, Sampang. Sidoarjo, and Surabaya. Based on the history of destructive earthquakes, this area has experienced earthquake intensity ranging from V - VIII MMI.
K Keywords: *East Java, Seismic vulnerability index, HVSR, earthquake, mitigation*

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INTRODUCTION

The eastern part of Java Island is one of the areas in Indonesia that has a very high potential for geological disasters. The existence of a volcano that stretches in the south also increases the risk of disaster. Very active seismicity levels often result in building damage and loss of life. Tectonically, East Java is in a subduction zone, namely the boundary between two plates that collide with each other, the oceanic plate subducts the continental plate. The subduction zone in the south of the island of Java often produces large earthquakes and has the potential for tsunamis. Generally, earthquakes with large strengths originate from the megathrust zone, which is a subduction zone that has a gentle dive angle to depth.

Based on physiography, East Java is part of the Sunda arc which stretches for 5600 km from the Andamans in the northwest to the Banda arc in the east. Then the zone continues to Maluku to North Sulawesi with different names [1]. In East Java, the Indo-Australian plate movement is relatively perpendicular to the axis of Java Island at a lower speed than in Sumatra, which is only about 4.9 cm/year to 6.0 cm/year [2]. The continuous subduction of plates causes the formation of normal and rising fault patterns that are parallel to the island arc.

Figure 1 shows that in general East Java, which is marked with a red line, is dominated by ascending fault structures such as the Kendeng fault and descending faults such as Pasuruan, Probolinggo, and Baluran. The Kendeng Fault stretches from Central Java to East Java in a west-east direction. This fault is continuous with the Semarang fault to the Baribis fault. The level of seismicity in the East Java area is quite high, which is indicated by dots of different colors indicating different depths. It can be seen that the source of earthquakes is not only from the subduction zone (black line along the Indian Ocean), but in recent times earthquakes with moderate magnitude (3 < M < 5) to large scale (M > 5) often occur in along the Kendeng fault zone [3].

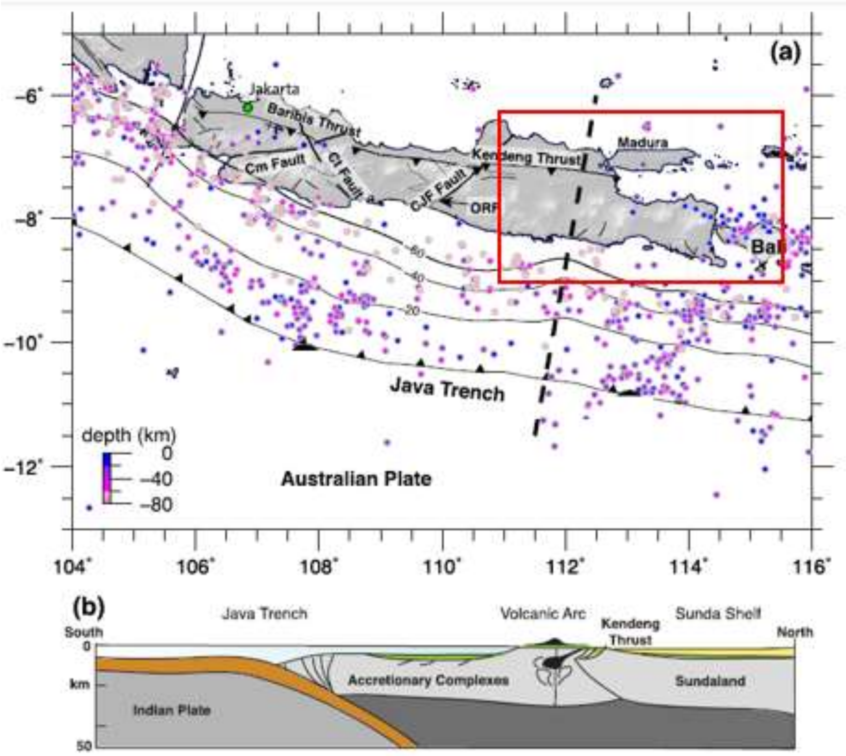

Figure 1. The Kendeng fault extends along eastern to central Java, the red line is the research area (Koulali et al, 2016).

This needs to be a concern for the community, especially those in the East Java region to continuously improve preparedness in dealing with the threat of disaster (hazard). Community preparedness in dealing with disasters is needed to reduce the risk of disasters caused. Disaster risk is influenced by external threats, vulnerabilities, and community capacities. The risk will be high when threats and vulnerabilities are high while capabilities are low.

One of the efforts to reduce disaster risk is through mitigation. Disaster mitigation can be initiated by conducting a study based on the geological conditions of the local area. Soil vulnerability studies are the first step to determine the level of disaster risk in an area when an earthquake occurs. The purpose of this study was to determine the level of disaster risk in East Java based on the seismic vulnerability index (Kg).

METHOD

The research area is focused along East Java and Madura with coordinates 111,00 east longitude – 114,40 east longitude and 7,12 south longitude – 8,48 south longitudes. Administratively, it is included in East Java Province which has an area of 47,157,157.72 Km2. It is bordered by the East Java region to the north by the Java Sea, to the east by the Bali Strait, to the south by the Indian Ocean, and to the west by the Province of Central Java.

This study uses secondary data in the form of passive seismic signal recordings (ambient noise) consisting of 27 broadband type seismometers three components CMG-3T seismograph network belonging to the Meteorology, Climatology and Geophysics Agency (BMKG), 17 short-period seismometers with three components Mark-L4- The MERAMEX (MERapi Amphibious Experiment) 3D seismograph network, and 56 trillium compact and Lennart 3D Lite portable seismographs are operated by the Australian National University (ANU) and BMKG. Each point is collected data for 24 hours.

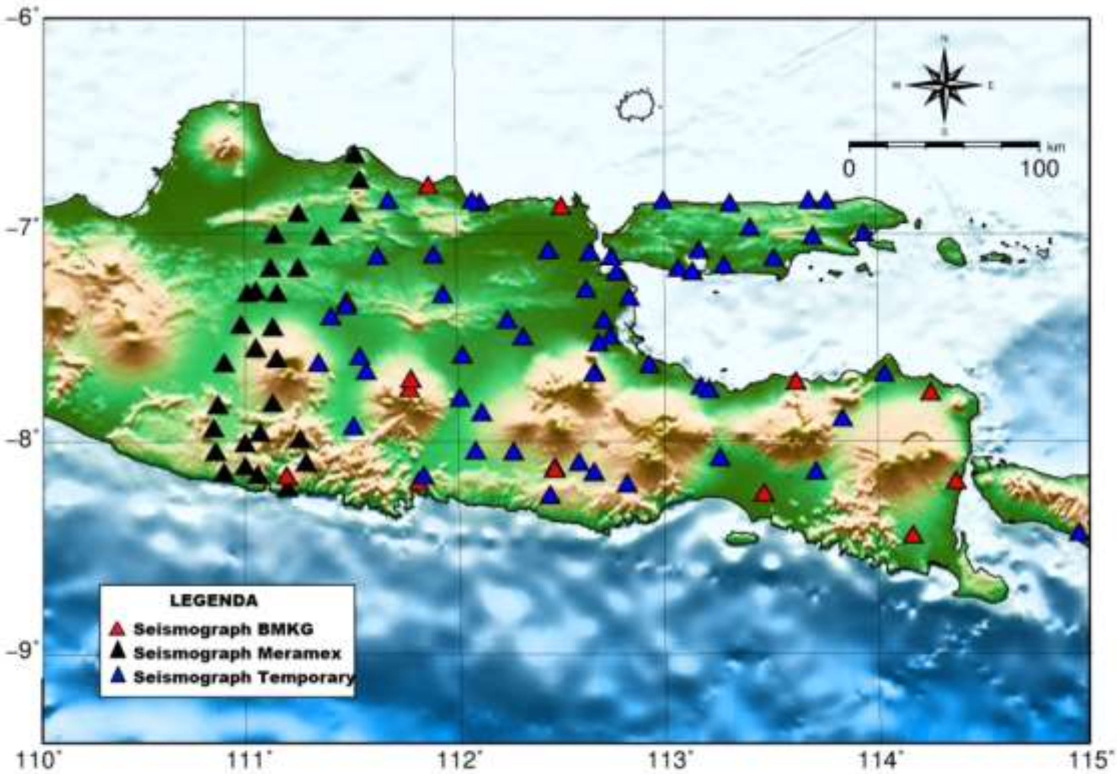

Figure 2. Seismograph network of research area, BMKG seismograph (red triangle), Meramex seismograph (black triangle), and Temporary seismograph (blue triangle).

Ambient noise analysis uses the HVSR technique, which is a comparison between the spectrum of the horizontal component to the spectrum of the vertical component. HVSR data processing using Geopsy software. Geopsy is software that is commonly used in seismic data processing. Mainly for determining the HVSR spectrum. The tools presented are very easy to understand making it easier to perform data processing. In

Geopsy, the steps in calculating HVSR in general are signal data input, parameter settings, windowing, Fourier transformation, smoothing, and h/v curves.

The determination of the peak of the h/v curve follows the criteria of the European Research Project's SESAME recommendation (2004) regarding the reliability criteria and the clear peak as a reference in determining the h/v curve [4]. Reliability criteria consist of three. First, the natural frequency is greater than 10 divided by the length of the windows (lw). Second, the number of significant cycles is greater than 200 (nc (fo) > 200). Third, the standard deviation of the amplitude (h/v) as a function of frequency for 0.5fo < f < 2fo is less than 2 if fo > 0.5 Hz and less than 3 if fo < Ao/2 at a frequency between fo/4 and fo. Second, it has Ah/v (f+) < Ao/2 at a frequency between fo and 4fo. Third, the amplification value at fo is more than 2. Fourth, the tolerance limit for fo is 5%. Fifth, the standard deviation of the frequency is smaller than the threshold limit (ε(fo)). Sixth, the amplification standard is smaller than the threshold limit (θ(fo)).

Furthermore, the analysis of soil characteristics is carried out by calculating the Seismic Vulnerability Index (Vulnerability Index). Nakamura (2000) provides an equation for the soil vulnerability index (Kg) as in equation (1)[5]. From the results of the analysis, the distribution of natural frequencies, soil amplification and vulnerability levels as well as their association with geological conditions in the study area will be known.

$$K_g = \frac{{A_0}^2}{F_0} \tag{1}$$

Where Kg is soil susceptibility index, Ao is soil amplification and fo is natural frequency. From the results of the analysis, the distribution of natural frequencies, soil amplification and vulnerability levels as well as their association with geological conditions in the study area will be known.

RESULTS AND DISCUSSIONS

The natural frequency or also known as the dominant frequency is the number of vibrations or waves formed in a unit of time. According to Nakamura (2000) natural frequency is influenced by the average velocity and depth of bedrock. The natural frequency has a value that is directly proportional to the average velocity and inversely proportional to the bedrock depth. Areas that have low natural frequency values are associated with sedimentary rocks and high natural frequencies are associated with bedrock. Sato et al (2004) conducted a study on the characteristics of the natural frequency values of ambient noise recordings based on geomorphological conditions [6]. Geomorphologically, hilly areas have a higher natural frequency than the transitional areas between hills and plains. Meanwhile, alluvial plains have lower natural frequency values.

Natural frequencies in East Java and Madura range from 0.3 Hz to 5.5 Hz as shown in Figure 4.10. In general, the Kendeng Zone has a relatively lower frequency value than the Rembang and Southern Mountains zones. The highest frequency value is in the southern mountainous zone which is directly adjacent to the Indian Ocean. The Rembang zone in the north of the study area has a slightly higher frequency value than the Kendeng zone, indicated by the presence of Mount Lasem.

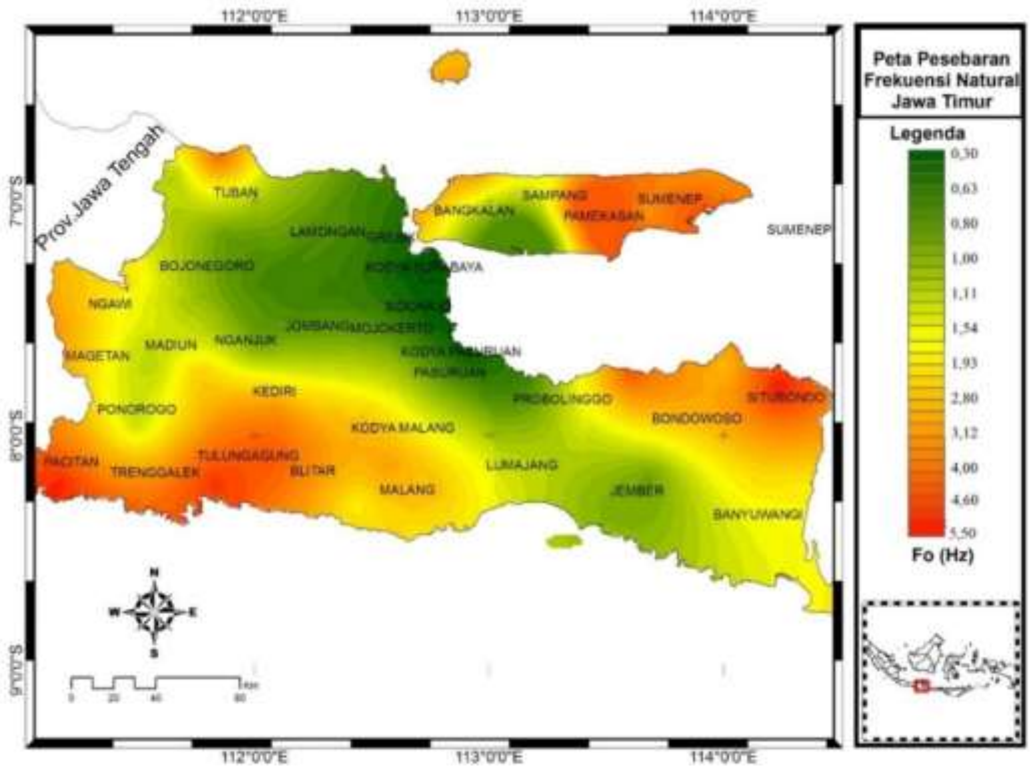

Figure 3. East Java Natural frequency distribution map.

Based on Figure 3, the natural frequency of the Kendeng zone ranges from 0.3 Hz to 1.5 Hz. The Kendeng Zone includes Magetan, Ngawi, Madiun, Bojonegoro, Nganjuk, Jombang, Surabaya City, Sidoarjo, Mojokerto, City and Regency, and Pasuruan. The natural frequency distribution is relatively lower in the east and increases towards the west and south of this zone. In general, the Kendeng zone is composed of alluvial plains in the east to the west bordering the Lawu mountains (Figure 3.1). Areas that have a natural frequency of less than 0.8 Hz are Surabaya, Sidoarjo, and Pasuruan. According to Kanai (in Subardjo, 2005) this area is classified as Type I type IV, composed of alluvial deposits formed from deltaic sedimentation, top soil and others. The thickness of the sediment layer is very thick ranging from 30 m to more than 200 m [7]. Even according to Smyth (2005) the depth of bedrock is not defined because it is covered by a very thick layer of sediment ranging from 8 km to 11 km [8].

The map of the distribution of the amplification factor in the East Java region shown in Figure 4 shows that the distribution of the highest amplification values is around Sidoarjo, Surabaya, and Gresik. While on the island of Madura, the distribution of the highest amplification factor is around Pamekasan. The value of the amplification factor in this region ranges from 3 – 5.90. High amplification factors are associated with low natural frequencies (Figure 3) and are closely related to local geological conditions. Areas that have a high amplification factor value (A0> 3), have the greatest risk of building damage during an earthquake (Nakamura, 2000) [5]. However, the amplification factor parameter is not sufficient to be able to conclude the level of vulnerability in an area, other parameters such as the vulnerability index are needed which provide information between the natural frequency and the amplification factor.

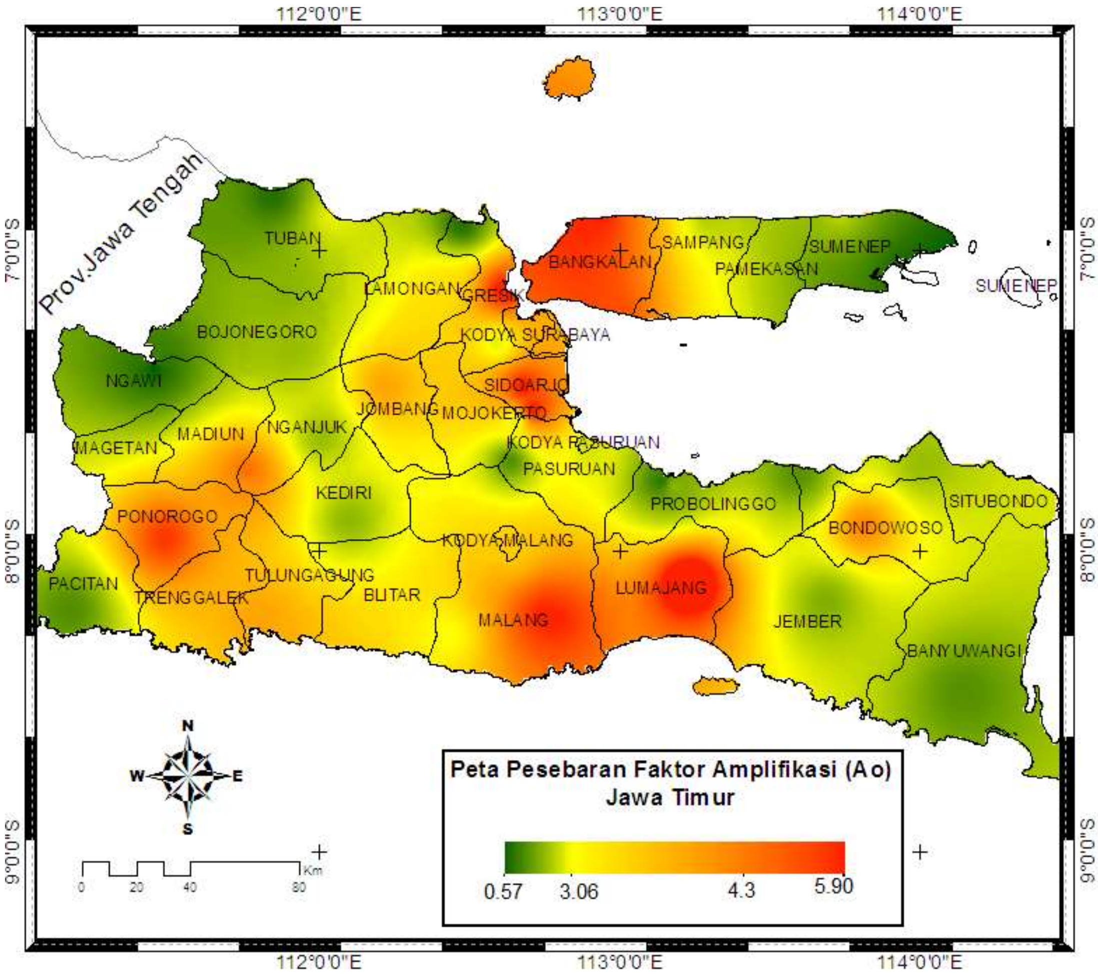

Figure 4. East Java amplification factor distribution map.

In general, hilly areas have relatively lower amplification factor values. This is in accordance with the research of Sato et al. (2004) who concluded that hilly areas have lower peaks of the h/v spectrum [6]. Areas that have a low amplification factor (A0 < 1) are Pacitan, Ponorogo, Tuban, Banyuwangi, Bondowoso, and Sidobondo. On the island of Madura dominated by low amplification factor values, associated with high natural frequencies. These areas include Sumenep, Sampang, and Bangkalan.

Seismic susceptibility index is influenced by sedimentary rock lithology, age of sedimentary rock, thickness of sedimentary layer, and depth of ground water table [9]. In addition, geomorphological conditions also greatly affect the seismic vulnerability index. Coastal areas, swamps, and reclamation have a high index of seismic vulnerability, while hilly areas have a very low index of seismic vulnerability. Damage to buildings due to earthquakes has a relationship with the seismic vulnerability index. Many studies have conducted studies between the areas affected by the earthquake and the distribution of the seismic vulnerability index. The results of the study concluded that areas experiencing the worst damage had a high seismic vulnerability index, while areas experiencing minimum damage had a low seismic vulnerability index. In addition, areas with a high seismic vulnerability index are prone to liquefaction.

The results of the study show that the East Java region has a seismic vulnerability index between 0.25 to 63.82. Figure 5 shows the distribution of the high vulnerability index in the areas of Sidoarjo, Surabaya, and Gresik which are marked by red gradations.

Areas that have a seismic vulnerability index between 6 and 30 are Pasuruan, Mojokerto, Jombang, Lumajang, Kediri, Tulungagung, Blitar, Malang, Jember, Bangkalan, Pamekasan and Sampang. Meanwhile, areas with a low seismic vulnerability index include Tuban, Bojonegoro, Ngawi, Magetan, Madiun, Ponorogo, Pacitan, Trenggalek, Banyuwangi, Bondowoso, Situbondo, and Sumenep.

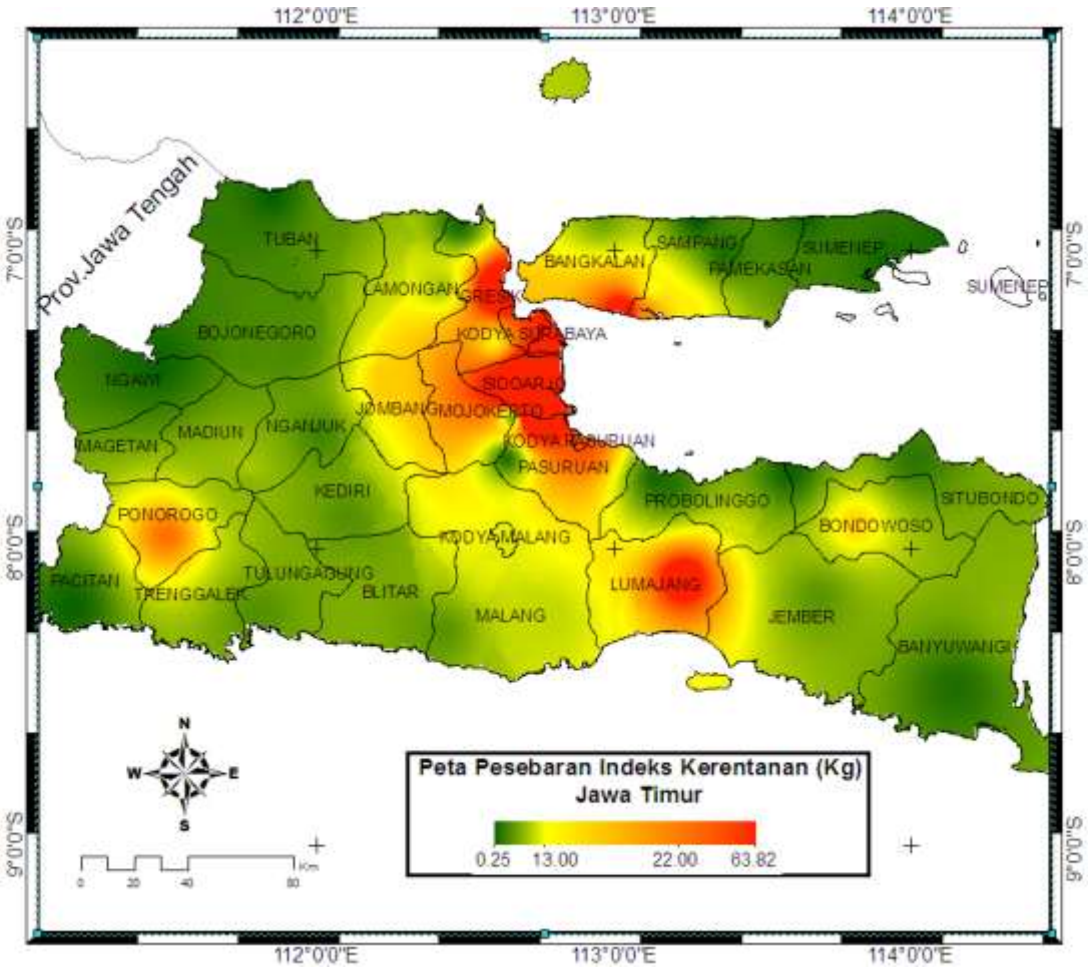

Figure 5. Map of the distribution of the East Java Soil Vulnerability Index.

Based on the history of the earthquake-affected area from 1799 – 2010 (Nguyen., N, et al., 2015) and the catalog of significant and destructive earthquakes in 1821-2017 (BMKG Earthquake and Tsunami Center, 2017) shows the strength of the intensity of earthquakes that occurred in the Java region. East ranges from III to IX MMI. This means that the level of damage caused by the earthquake is quite severe. The intensity of the earthquake with a strength of V – IX MMI indicates that the buildings of the structural and non-structural categories are damaged. In general, the earthquake-affected area is in an area of yellow to red color gradation (Figure 6). This supports the results of the study that the seismic vulnerability index is correlated with the level of earthquake risk. The higher the seismic vulnerability index, the greater the level of disaster risk. Therefore, disaster preparedness needs to be improved, especially for areas that have a high level of disaster risk.

In addition, the seismic susceptibility index greatly affects the response of rocks to the propagation of earthquake waves. The propagation of earthquake waves will experience attenuation with respect to the propagation distance. However, when the area has a higher seismic vulnerability index, it will experience a strengthening of earthquake waves or what is known as the local site effect.

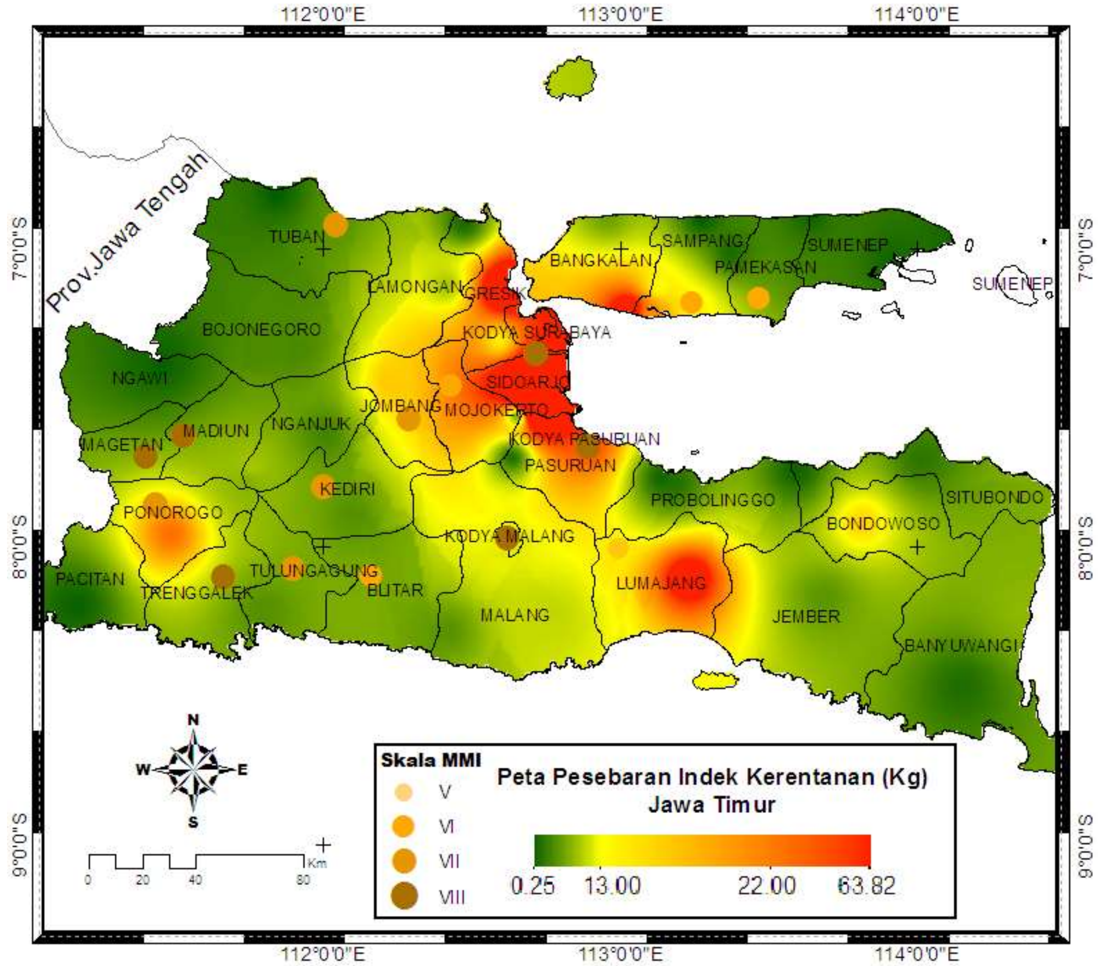

Figure 6. The history of the area affected by the earthquake and the distribution of the seismic vulnerability index in the East Java region.

CONCLUSIONS

East Java's natural frequency distribution ranges from 0.27 to 6.74 Hz, the amplification factor ranges from 0.57 to 7.18 times the wave amplification, and the seismic vulnerability index ranges from 0.23 to 64.44. Areas that have a high level of earthquake risk seen from the distribution of the seismic vulnerability index (Kg) include Lumajang, Malang, Pasuruan, Mojokerto, Sidoarjo, Surabaya, Gresik, Jombang, Ponorogo, Bangkalan, and Sampang. Areas that have a high level of earthquake risk are expected to increase preparedness, especially in regional spatial planning (RTRW) in order to reduce building damage due to earthquakes.

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