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Horizontal-to-Vertical Spectral Ratio (HVSR) Method for Earthquake Risk Determination of Jakarta City with Microtremor Data

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Horizontal-to-Vertical Spectral Ratio (HVSR) Method for Earthquake Risk Determination of Jakarta City with Microtremor Data

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Abstract. Jakarta is the capital of the Republic of Indonesia which lies above a thick sedimentary basin. Geographically, Jakarta is 200 km away from the Indo-Australian subduction zone that sinks under the island of Java. There are many vital buildings and with the thick sediments underlying the city of Jakarta. Therefore, this region has a considerable seismic vulnerability. This will be dangerous if there is an earthquake that has the same frequency as the natural frequency of the building. It will cause a resonance resulting in amplification of seismic waves in the area. Each building has a different natural frequency, one that affects is the height of the building. To characterize the subsurface structure of the Jakarta Basin, microtremor data processing was obtained from the recording of 95 stations which was operated in October 2013 - February 2014 using Horizontal-to-Vertical Spectral Ratio (HVSR) method. HVSR is a method for obtaining subsurface information from single station measurements by comparing the Fourier spectrum of horizontal components to its vertical components. This ratio is a function of the frequency that will produce the H/V curve. The dominant frequency value on the HVSR curve represents the natural frequency of the area. The Seismic Vulnerability Index (K_g), which serves to determine the soil weak zone, can be calculated from the H/V curve. The dominant frequency value maps generated for the Jakarta area range from 0.2-0.22 Hz for low frequencies and 1-8.6 Hz for high frequencies. The large dominant frequency correlates with the thin sediment layer. Based on the frequency range, the south and northwest regions of Jakarta have relatively shallow basement depths compared to other regions. The resulting amplification value map can be divided into 4 maps with different period ranges. From the four maps, the North Jakarta area or the area around Jakarta's coastline is most at risk of amplification with an H/V value up to 11 because the area is associated with alluvial deposits and coastal sediments. The seismic vulnerability distribution map in Jakarta City ranges from 15-850 relatively high in northeast and north of Jakarta.

1. Introduction

Jakarta is the capital of the Republic of Indonesia which is famous as a very dense city and lies in the sedimentary basin. By 2017, Jakarta was ranked 9th as the world's most populous city with a population of 9,600 inhabitants per km^2. In addition, the Jakarta area is also a part of Java Island which is a volcanic archipelago as a result of a meeting between the Indo-Australian oceanic plates that

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pierce at a speed of 6 cm/year under the Eurasian continental plate [5]. The subduction of these two plates is the Benioff seismic line, which dips northward at a distance of 200 km from Jakarta [6]. This will be dangerous if earthquakes happen, a thick sedimentary basin will cause amplification on the ground so that the damage it causes will be quite severe. Therefore, the prediction of seismic dangers needs to be done in Jakarta as a form of disaster mitigation to reduce the losses that will be generated in the event of future disasters.

2. Geology

Jakarta, on mid-Miocene, was a shallow sea that has the majority of limestone lithology, then at the late Miocene, Jakarta became a coastal area that deposit sand-clay lithology [8]. Later on the Pliocene, the magmatic arc moved toward the middle of Java Island which causes on the Pliocene-Pleistocene West Java lifted so the Jakarta area became the foot of the mountain and that caused the material that comes will be deposited as alluvium fan deposits in the river that flows into the Java Sea. Jakarta is an area where the sediment layer is thick enough. The geological history is summarized in the stratigraphic map by [14].

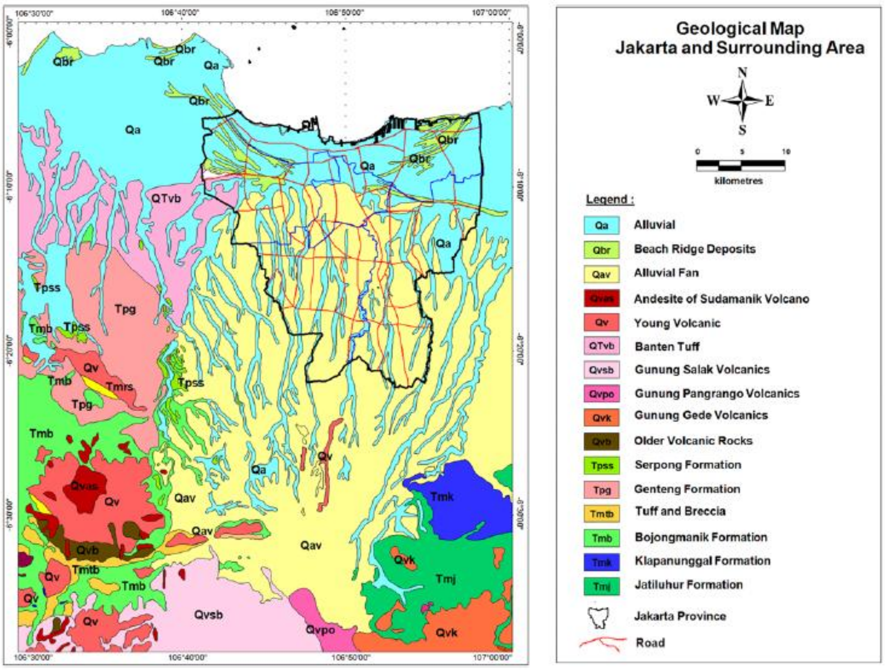


Figure 1. The stratigraphic map of the city of Jakarta and its surroundings was [12].

3. Data and Methods

3.1. Data

The data used in this research is the recording data of microtremor of Jakarta Basin from 95 stations covering all area of Jakarta City. Microtremor data retrieval was conducted in October 2013-February 2014 by [2] with station distribution in Fig.1. The seismometer used in microtremor recording is a 3-component fixed-temporary and temporary broadband seismometer. Temporary location of seismometer displacement is done every one month with a distance between location 1-5 km. The recording is done for 24 hours but the data which is processed only data at night, around 21:00 until 03:00 to avoid noise caused by local activities (Figure (2)).

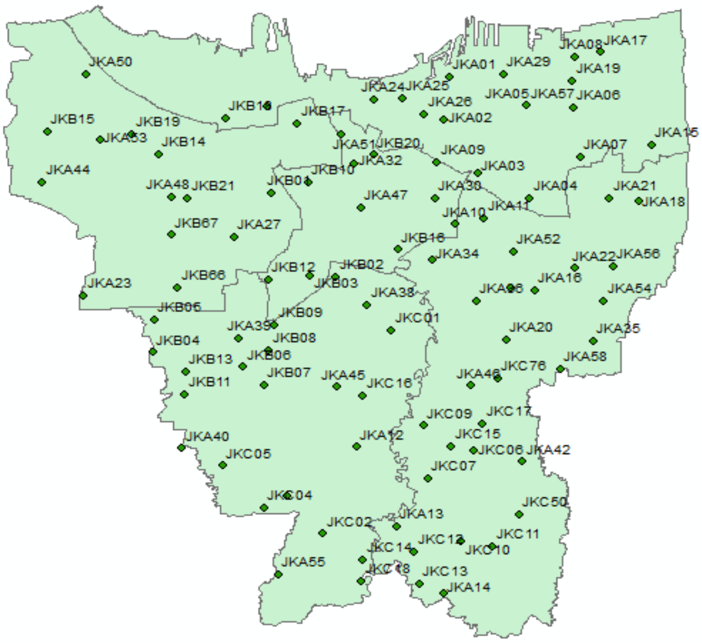


Figure 2. Microtremor research location in Jakarta area

3.2. Methods

The Horizontal-to-Vertical Spectral Ratio (HVSR or H/V) method is one of the methods for obtaining subsurface information from single station measurements initially used to investigate the risk of seismicity in Japan [9, 11]. HVSR applications can be performed on soft sedimentary layers. The result of HVSR is the amplification factor and dominant frequency value. Amplification can occur because the wave is trapped in the basin and the wave is reflected so that the phenomenon of constructive interference occurs. The predominant frequency value of HVSR expresses the natural frequencies contained in the area. In the event of an earthquake or vibration having the same frequency as the natural frequency, resonance will occur resulting in amplification of seismic waves in the area. Data acquisition on this method requires a 3 components station that serves to perform the comparison of the Fourier spectrum of horizontal and vertical components. Assuming the H/V in the bedrock is 1, because the waves propagating in the same vertical and horizontal direction, the H/V ratio can be written as

$$H/V = \frac{A_H}{A_V} \tag{1}$$

From equation (1), A_H and A_V are horizontal and vertical Fourier spectrum. This ratio is a function of the frequency that will produce the H/V curve. The Seismic Vulnerability Index (K_g) was proposed by Nakamura in 1996 to estimate the damage caused by earthquakes based on soil layers and structures. K_g, written as equation (2), serves as an index of vulnerability of an area that can be useful in determining the weak zone of the soil.

$$K_g = \frac{A_g^2}{F_g} \tag{2}$$

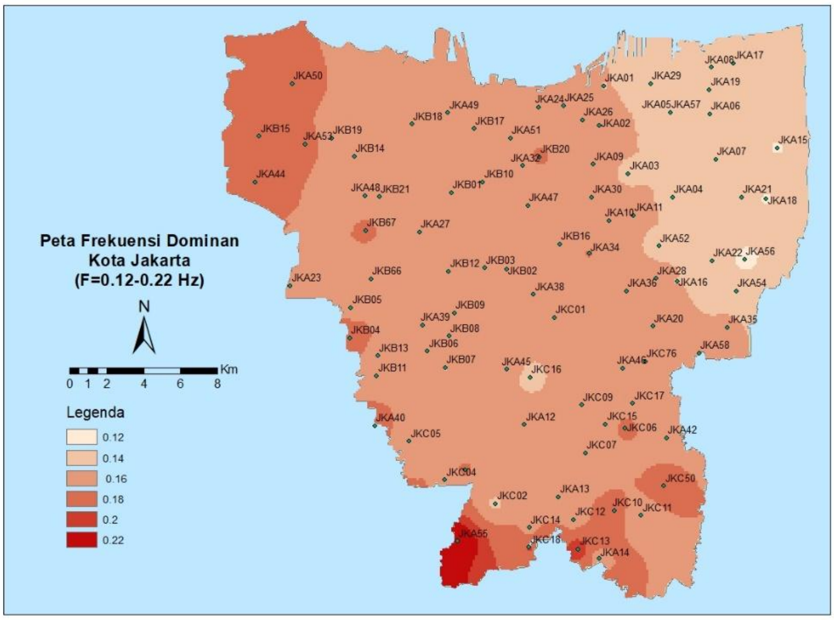
4. Results and Discussion

4.1. Dominant Frequency Maps

The dominant frequency distribution can be seen in Figure 3. In Figure 3 (a), the dominant frequency distribution is enlarged to southward and westward with a frequency range of 0.2-0.22 Hz. Dominant frequencies can be used to estimate the basement depth that can be attributed to the thickness of the sediment layer. The low dominant frequency values associated with the thickness of the sediments that form the terrain and the large dominant frequency values illustrate the increasingly thin thickness of the sedimentary layer [13]. The dominant frequency values in the southern high areas are also related to the highlands of Bogor and to the west with respect to the Tangerang Heights.

Figure 3 (b) is the dominant frequency map in the high-frequency range. A value 0 on the map is owned by a region with a single HVSR peak. The region has a rather small layer impedance contrast.

(a)



(b)

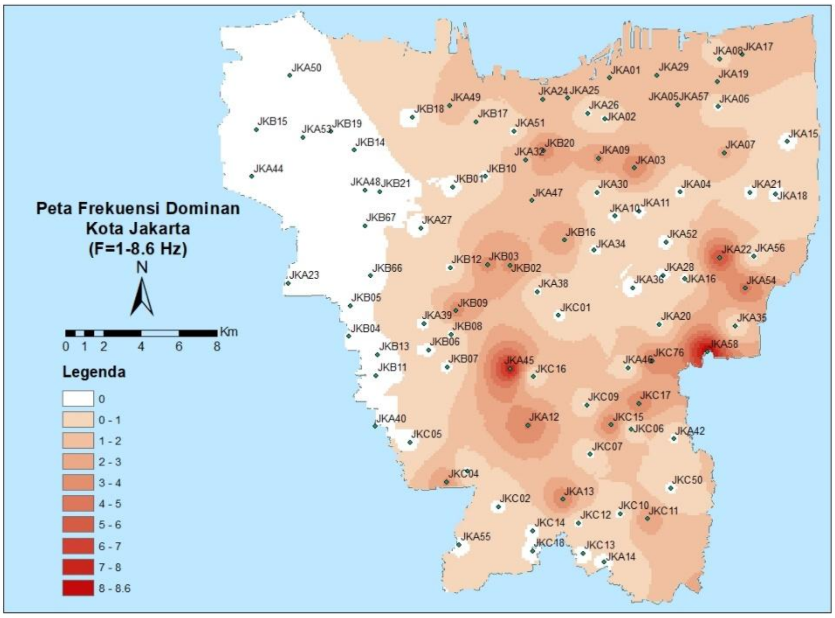


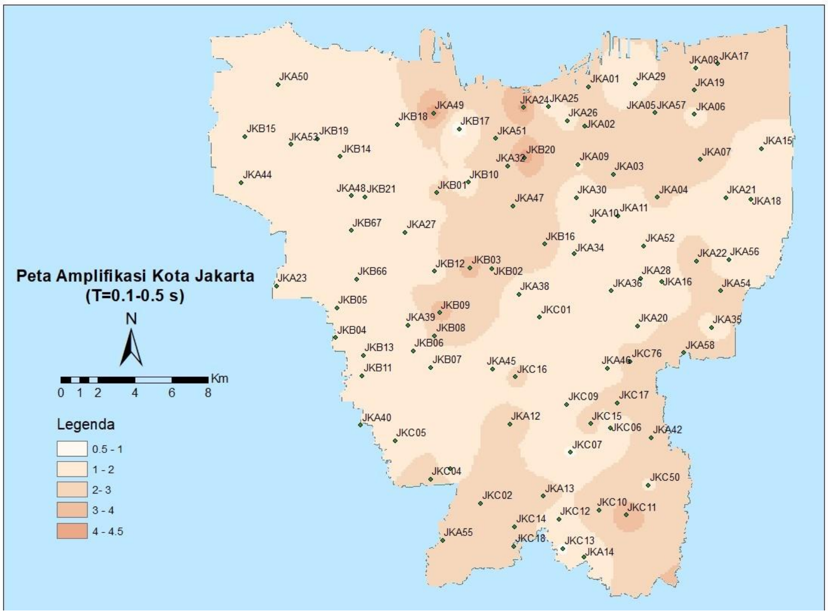
Figure 3. (a) Map of a dominant frequency with frequency range 0.12-0.22 Hz and (b) dominant frequency map in frequency range 1-8.6 Hz.

The high dominant frequency values are scattered in the central area of Jakarta City which is associated with the existence of alluvial fan deposits, so the contrast of the layer impedance is considerable.

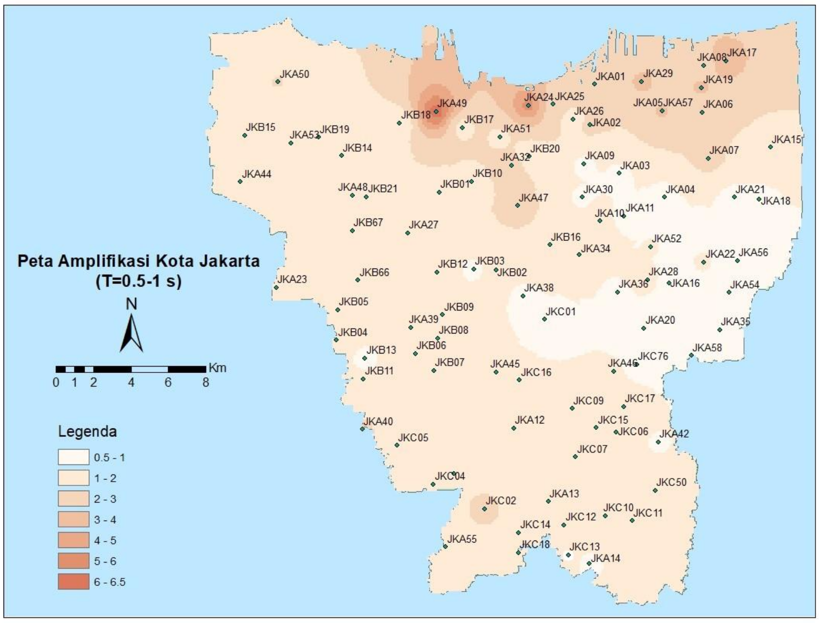
4.2. Factor Amplification Maps

Distribution of amplification values mapped into different period ranges based on [4]. Figure 4 (a) shows the amplification over a period of 0.1-0.5 seconds. The amplification value at that time period corresponds to the natural period of the house or one-story building. In the northern and southern regions, building a single floor building material is not very sturdy is very risky suffered severe damage because the amplification that occurs can reach 4.5 times from the vibration in the basement. Figure 4 (b) shows the amplification over a period of 0.5-1 seconds. The amplification value in that period is related to the natural period of the four-story building. In the northern area, a four-story building is at risk of damage because it can occur up to 6.5 times the amplification of vibrations in the basement.

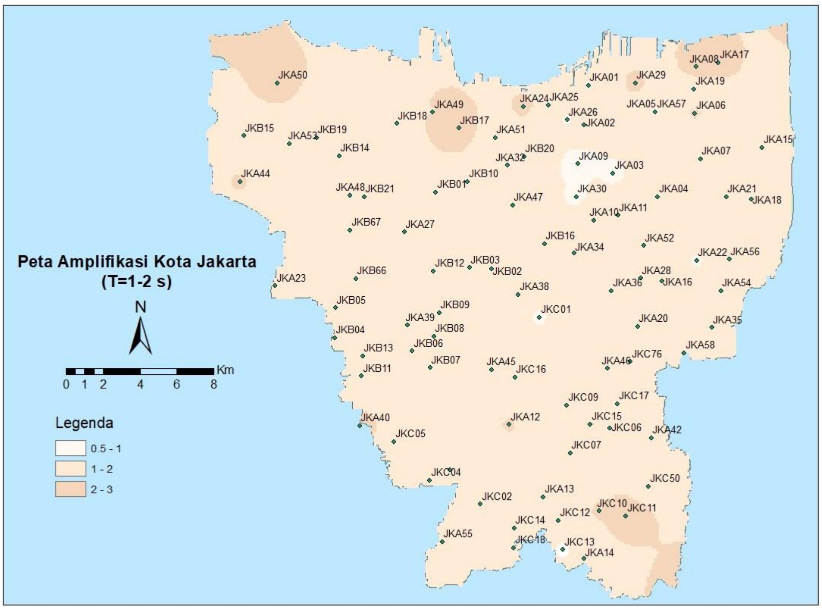
(a)



(b)



(c)



(d)

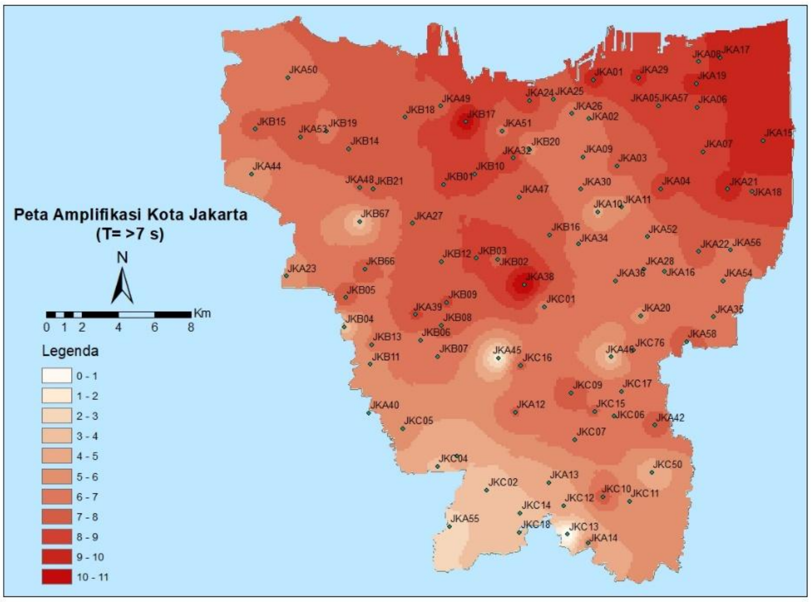


Figure 4. Map of amplification with different period ranges. (a) amplification maps with period ranges of 0.1-0.5 s, (b) 0.5-1 s, (c) 1-2 s, and (d) greater than 7 s.

Figure 4 (c) shows amplification over a period of 1-2 seconds. The amplification values in this period range relate to the building's natural period of 10 to 20 floors. In this period, the amplification is quite evenly distributed throughout the region that is 1-2 times that of the vibrations in the basement. In the north, there are several areas with greater amplification of 2-3 times, and high-rise buildings in those areas are most at risk of shocks.

Figure 4 (d) shows amplification over periods greater than 7 seconds. The amplification values in this period range relate to the natural period of buildings over 20 floors. In this period, the amplification is high in almost all areas of Jakarta. Low amplification is in the south. The northern, northeast, and northwest regions will experience very high amplification in case of an earthquake with a period greater than 7. Amplification that can occur can reach 10-11 times from the vibration in the basement. This is related to the geological conditions. The northern, northwest, and northeast parts of Jakarta are coastal areas composed of alluvial deposits and beach ridge deposits associated with marine origin landforms.

4.3. Seismic Vulnerability Maps

The distribution of seismic vulnerability values in Jakarta City ranges from 15-850. In general, relatively high distribution values are found in the northeast and north (Figure (5)). The value distribution is high because the area is coastal. The relatively low K_g value is distributed in the eastern and southern parts of Jakarta. The high-value seismic susceptibility index is associated with alluvial depositional facies, while the low-value index is associated with hard rock [3]. [10] also mentioned the same thing that coastal areas have high seismic vulnerability because they are alluvium deposits and the area is severely damaged during an earthquake precisely in the Marina District of Mexico.

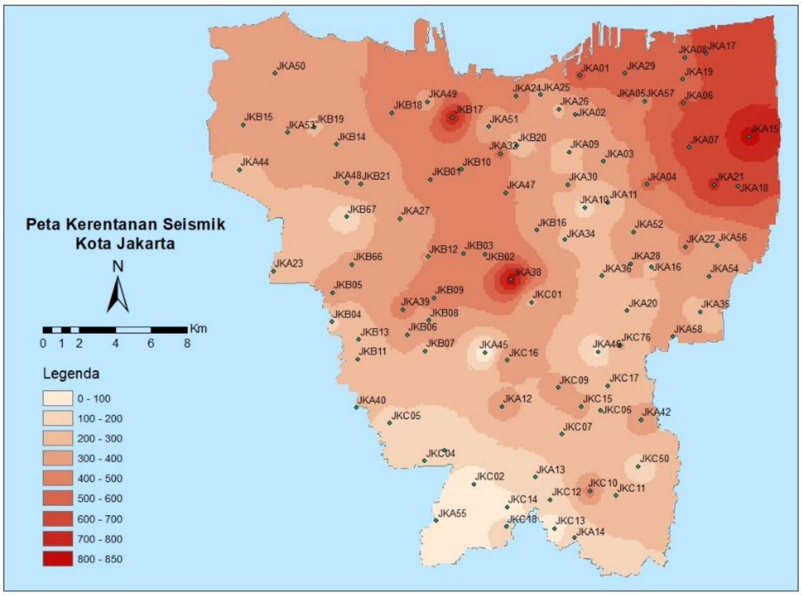


Figure 5. Map of seismic vulnerability of Jakarta City

From this seismic vulnerability index, the γ shear strain of the surface can be estimated. According to [7], the relation γ to disasters that can occur on the surface can be written as in Table 1. The table indicates that from $\gamma = 1000\times10^{-6}$ the ground surface begins to show nonlinear behavior and at $\gamma = 10{,}000\times10^{-6}$ large deformations and collapse may occur.

Table 1. The effect of strain on soil properties [7]

Size of Strain	10^{-6} 10^{-5}	10^{-4} 10^{-3}	10^{-2} 10^{-1}
Phenomena	Wave, Vibration	Crack	Landside
dynamic	Elasticity	Elasto-Plasticity	Collapse Repeat-Effect, Speed-Effect of Loading

Based on the Peak Ground Acceleration (PGA) map of Indonesia [1], the value of PGA in the Jakarta area ranges from 300-400 gal. Assuming V_b = 600 m/s and α_b = 300 gal, for $K_g \geq 15$ we get $\gamma = 7.59 \times 10^{-3}$ and for $K_g \geq 800$ we get $\gamma = 4 \times 10^{-1}$. From the value of the shear strain, if there is an earthquake in Jakarta, the damage that may occur is cracks and settlements until there can be liquefaction. North Jakarta is at risk of liquefaction, while southern Jakarta is at risk of cracks and settlements. However, other data such as more detailed geological data are needed to reinforce the possibility of such a disaster.

5. Conclusion

Based on the dominant frequency value, the greater the dominant frequency the thickness of the sediment is thinner, and vice versa. The south and northwest areas of Jakarta have a relatively thin thickness of sediments. From the 4 amplification maps, the North Jakarta area or the area around Jakarta's coastline is most at risk of amplification up to 11 times in the event of an earthquake. This is related to the geological condition of the area composed of alluvial deposits and beach ridge deposits. The distribution of seismic vulnerability values in Jakarta City ranges from 15-850. In general, relatively high values are found in northeastern and northern Jakarta.

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