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Microzonation Analysis in Manna City & Pasar Manna Subdistricts Utilizing Microtremor Data, South Bengkulu Regency

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Abstract

South Bengkulu is prone to earthquakes because it is located on the Great Sumatran Fault. Apart from that, it is also influenced by the activity of the Musi and Manna segments, so that besides being influenced by the two active tectonic plates it is also influenced by the local segment. This research is located in Manna City and Manna Market, which is mostly inhabited by people and is the capital of South Bengkulu. In connection with infrastructure development, it is necessary to know the condition of the soil layers to minimize the risk of building damage due to earthquakes. This research aims to analyze earthquake-prone areas based on dominant frequency parameters, soil amplification, seismic vulnerability index and sediment layer thickness (h). Research data comes from microtremor measurements at 60 measuring station points in Manna City and Manna Market. The tool used is a Short Period Portable Seismometer Model Gemini 2 SN-1405. This microtremor data is processed using the Horizontal to Vertical Spectral Ratio (HVSR) method. The results of data processing show that the research area has the lowest dominant frequency of 3.95 Hz and the highest of 49.71 Hz. The ground vibration amplification value is classified as small to medium, the lowest is 1.3 and the highest is 5.19. The lowest earthquake vulnerability index was 0.18 cm2/s and the highest was 2.24 cm2/s. The smallest sediment thickness was 3.77 meters and the thickest was 47.48 meters. From the results of the calculation of the seismic vulnerability index in Kota Manna and Pasar Manna Districts, the seismic vulnerability index value is relatively small, in accordance with the amplification factor and the thickness of the sediment layer. Based on this research, although Manna City and Manna Market are often shaken by earthquakes, the earthquake vibrations experience small amplification.

Introduction

Bengkulu Province is located around a subduction zone formed by the collision of the Eurasian and Indo-Australian plates. Two significant faults in Sumatra border this area: the Musi and Manna [1]. Earthquakes in this area are not only caused by tectonic plate confluence but are also triggered by the subduction system and the Sumatran fault, as shown in Figure 1. The consequences of these two earthquake sources can exacerbate the tectonic complexes and the Bengkulu region's vulnerability to earthquakes [2].

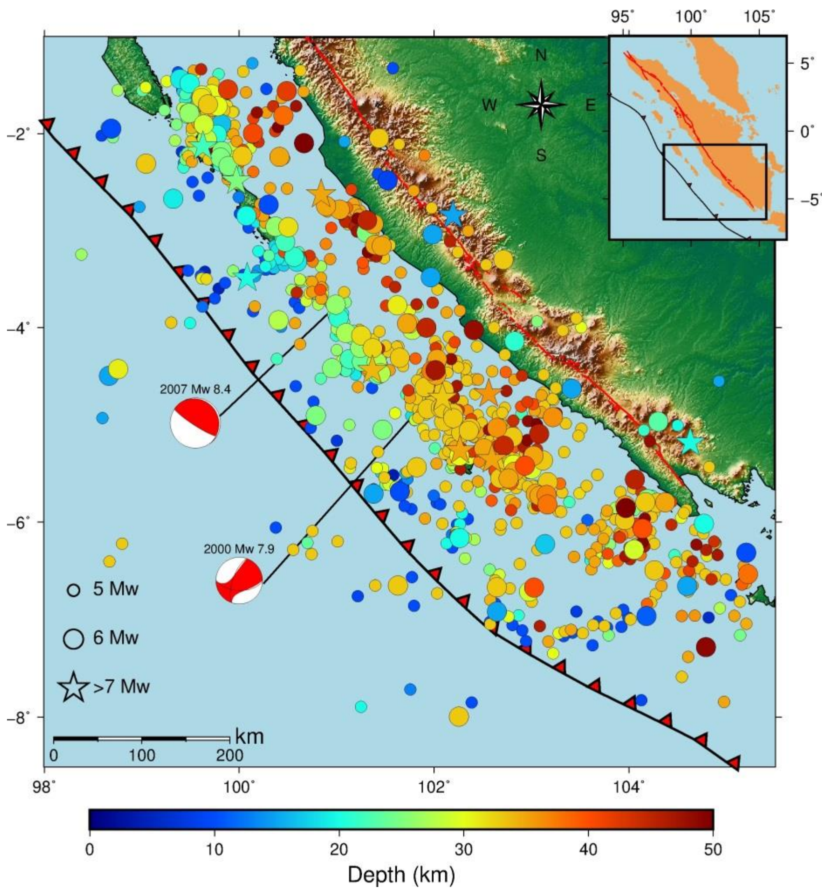

Figure 1. Seismicity map of the research area and environs during 1922–2022 [3].

Damage due to earthquakes depends not only on the quake's strength. Still, it is also influenced by local geological conditions, which are very significant for damage caused by earthquakes [4]. Areas subject to injury due to earthquakes contain a heavy layer of sediment sitting on top of a layer of hard rock [4,5]. The greater the thickness of the sediment layer in an area, the more significant the impact of the earthquake will be [6]. This is because sites with a thick layer of sediment have rock characteristics that are not solid, so they are easily deformed in a big earthquake [7]. Figure 2 shows an example of the aftermath of an earthquake in the Special Region of Yogyakarta in 2006, which caused more than 100,000 houses to be severely damaged [8].

Figure 2. An example of the aftermath of an earthquake in the Special Region of Yogyakarta in 2006 (left) and an example of damage caused by the earthquake of Bengkulu in 2007

South Bengkulu is one of the Regencies in Bengkulu Province, which is above a basin formed by sedimentary rock material deposits consisting of quartz, feldspar, and rock fragments, and has topographical conditions of 50.93% lowlands, 43% hilly areas, and 6.07% the area leads to the top of Bukit Bukit Barisan mountain range [9]. In this region, especially the City of Manna, South Bengkulu Regency has a very rapid rate of population growth; infrastructure development will continue to be carried out in the future and will become an expansion of the center of the city of Manna. Before further development, it is necessary to study the advanced subsurface structure by knowing the thickness of the sediment layer and the level of seismic vulnerability in the area. This is done as an effort to deal with earthquake disasters. Carrying out earthquakes and analyzing the seismic vulnerability index (Kg) by detecting microtremors is one of the things that is being done to cut down on the risk of natural disasters. The data obtained on microtremor measurements are natural vibrations originating from nature and human activities [10].

The Horizontal to Vertical Spectral Ratio (HVSR) method is used in conducting microtremor analysis, and data processing using the microtremor method is used to estimate natural frequency values (f_0) and amplification (A_0) [11]. Furthermore, these two data are used to calculate the seismic vulnerability index (Kg) and sediment layer thickness (h). This research was conducted to support disaster mitigation efforts and reduce disaster risk in Kota Manna, South Bengkulu Regency. Based on microtremor data, this research analyzes the readiness of areas vulnerable to earthquake hazards and the availability of sediment layers in Kota Manna Subdistrict and Pasar Manna Subdistrict, South Bengkulu Regency.

Methodology

Provide sufficient detail to allow the work to be reproduced. Methods already published should be indicated by a reference. Only relevant modifications should be described. Microtremor data measurements were conducted in Kota Manna and Pasar Manna subdistricts, South Bengkulu Regency, Bengkulu Province. The information that was gathered was derived from the outcomes of measurements carried out at sixty different places, most of which were located in the southern portion of Manna City Subdistrict and Pasar Manna. The equipment is a set of *Portable Short Period Seismometer* Model Gemini 2 SN-1405 to record ground vibrations, geological compass, GPS, camera, laptop, and software such as Geopsy and Qgis Software. The results of the microtremor recording are in the form of 3 component signal data (Vertical, North-South, and East-West.). Geopsy software analyzes the signal and carries out the HVSR process to obtain the dominant frequency value (f_0) and amplification value (A_0). The H/V curve is obtained as shown in Figure 3.

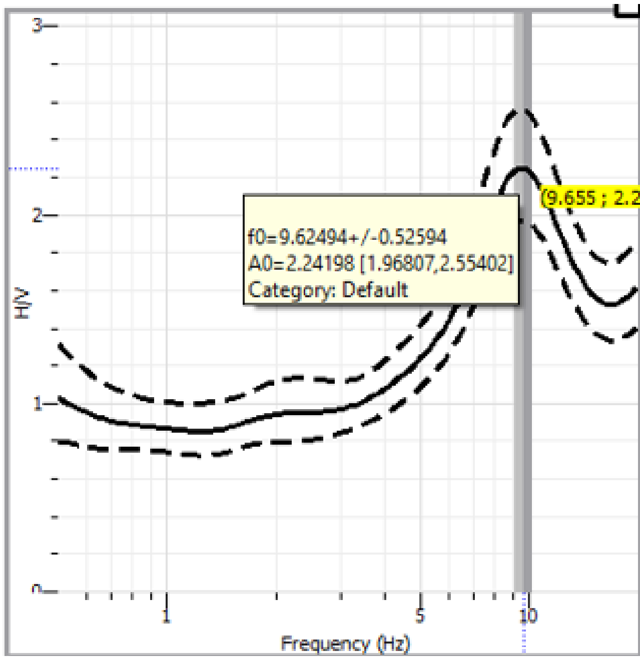

Figure 3. HVSR curves at measurement point T18.

The seismic vulnerability index (Kg) is obtained from the dominant frequency value (f_0) and the amplification factor (A_0) because the seismic vulnerability index (K_g) of an area provides an overview of the level of vulnerability of the soil layer to deformation that occurs due to earthquakes [11]. This value is calculated based on the following equation [12] :

$$Kg = \frac{(A_0)^2}{f_0} \quad (1)$$

Where A_0 is the amplification factor, and f_0 is the predominant frequency of the ground. After obtaining the value of K_g, the next step is to determine the thickness of the sediment layer with the following equation [10] :

$$h = \frac{V_s}{4f_0} \quad (2)$$

with the value of Vs as a representation of shear wave velocity on bedrock, $V_s=V_b$ with $V_b \approx 750$m/s based on SNI 03-1726-2019.

Then we made a distribution map of the predominant frequency (f_0), amplification factor (A_0), seismic vulnerability index (Kg) and sediment layer thickness (h) using Qgis software. The research flowchart can be seen in Figure 4**.**

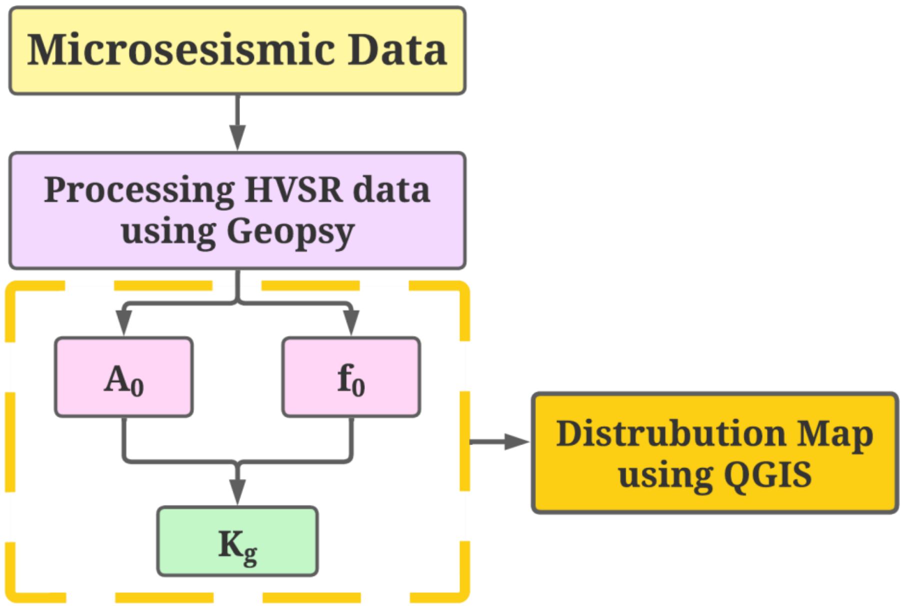

Figure 4. Data processing flowchart.

Result and Discussion

The topography map of the research area, which can be seen in Figure 5, was overlaid with the sixty research data points that were collected in the Kota Manna and Pasar Manna sub-districts of the South Bengkulu Regency. The employed topographic data has a resolution of 8 meters and was obtained from the Geospatial Information Agency (BIG) of Indonesia, DEMNAS (https://tanahair.indonesia.go.id/demnas/). The areas indicated by shades of dark green to blue have altitudes ranging from -7.2 to 28.9 meters; this is due to the fact that these regions are located relatively near the shoreline and rivers. In the meantime, the areas near coastal settlements that are yellow and have altitudes between 34.9 and 40.9 meters are shown. The yellow area, which has an elevation ranging from 35 to 48 meters, is a region with a medium elevation that is suitable for the growth of oil palm plantations. In addition, the region denoted by red to orange is located at an elevation ranging from 46.9 to 64.9 meters, which denotes the core of residential neighborhoods. And finally, the area shown in pink is the highest section of the Manna City area that is used as a plantation. It has an elevation ranging from 71.0 to 89.1 meters.

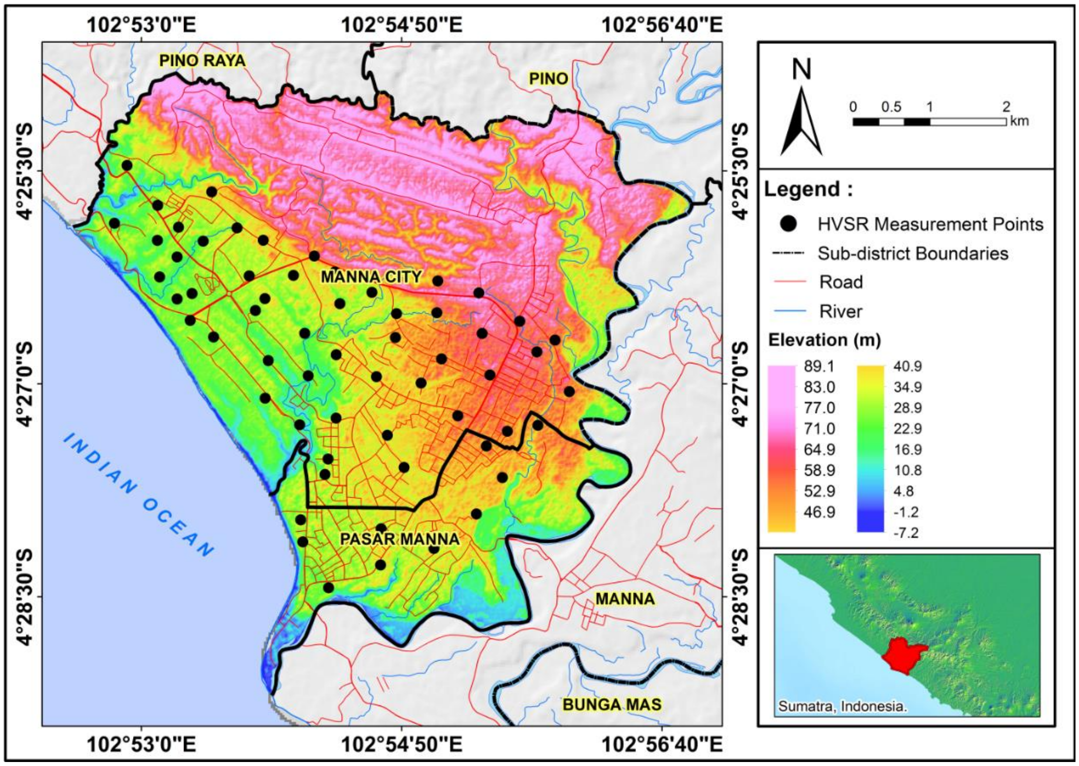

Figure 5. Study area elevation map with field data measurement points.

Based on the data obtained, the dominant frequency (f_0) in the study area ranges from 3.95 Hz – 49.71 Hz. The frequency values can be seen in the distribution map of the dominant frequency (f_0) in Figure 6. Two types of dominant frequencies are distinguished, namely types II and I. Based on the Kanai and Tanaka classifications, type II describes the sediment thickness category as medium with a thickness range of 5 to 10 meters [13]. Includes alluvial rock with a thickness of 5 meters, consisting of Sandy Gravel, sandy hard, clay, loam, and others. These types are spread almost throughout the research area. Type I describes a thin thickness of sediment that is less than 5 meters, dominated by hard rock composed of hard sandy rock, gravel, and others.

From the results of the research conducted, it appears that the majority of the research areas have a low level of dominant frequency (A_0) marked in green, so that in geotechnical studies this area is less recommended for the construction of high-rise buildings such as offices, hotels and housing for city expansion [14]. This is because the dominant frequency (A_0) is not aligned with the thickness of the sediment layer (h). On the map, the value of the dominant frequency (A_0) is lower closer to the coast because alluvial rocks in coastal areas generally have a low frequency. A low dominant frequency (A_0) indicates a thick sedimentary layer made of soft rock, while a high dominant frequency (A_0) indicates a thin sedimentary layer of hard rock.

If viewed from the topographic map of the study area Figure 5. The study area has a similar elevation because it is located in an area with low plains. The small dominant frequency area (A_0) is in a low topography ranging from 0-35 meters to the west approaching the coast. While the dominant frequency (A_0) is significant in medium to high topography. Therefore, low-frequency distribution (A_0) areas are associated with common topographical conditions.

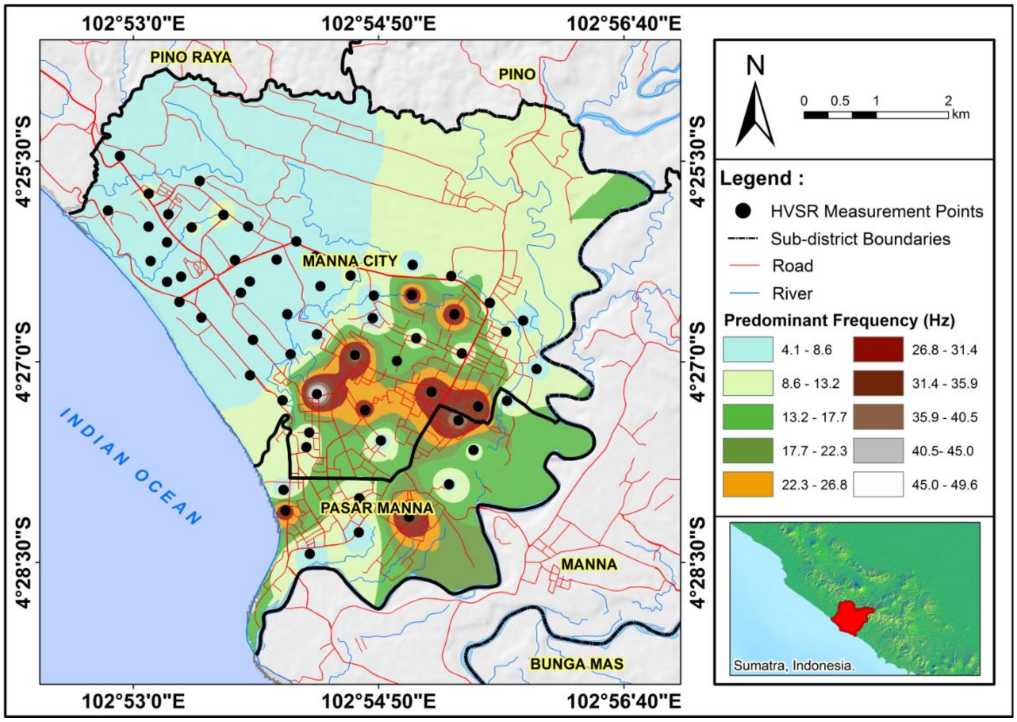

Figure 6. The predominant frequency distribution map in the study area is overlaid with field data measurement points.

The amplification factor values (A_0) distribution in the study area range from 1.43 to 5.19. The value of the amplification factor can be seen in the amplification factor distribution map (A_0) in Figure 7. According to the classification in Laberta's study, there are two classes of amplification factors, namely low and medium classes [15]. Common type (A_0 <3) indicates that this area is composed of solid rock, this class is spread almost throughout the study area. Another case with the middle class with an amplification between 3-6 indicates that the area is composed of not-too-dense rocks. The amplification (A_0) is affected by the wave speed, where if the wave speed in a medium is slow, the amplification will be high. Conversely, if the wave speed in the medium is fast, the amplification will be low. This shows that amplification is related to the level of rock density.

From the results of the research conducted, it can be seen that most areas of the City of Manna and Pasar Manna sub-districts in South Bengkulu Regency have a low level of amplification factor (A_0), which means that the likelihood of earthquake shaking and the risk that occurs is small. This indicates that the amplification factor (A_0) is related to the increase in vibration intensity and the level of risk that arises when an earthquake occurs. The higher the value of the amplification factor (A_0), the greater the vibration intensity and the resulting hazard. Conversely, if the value of the amplification factor (A_0) is low, the intensity of the vibration and the risk will also be smaller [7].

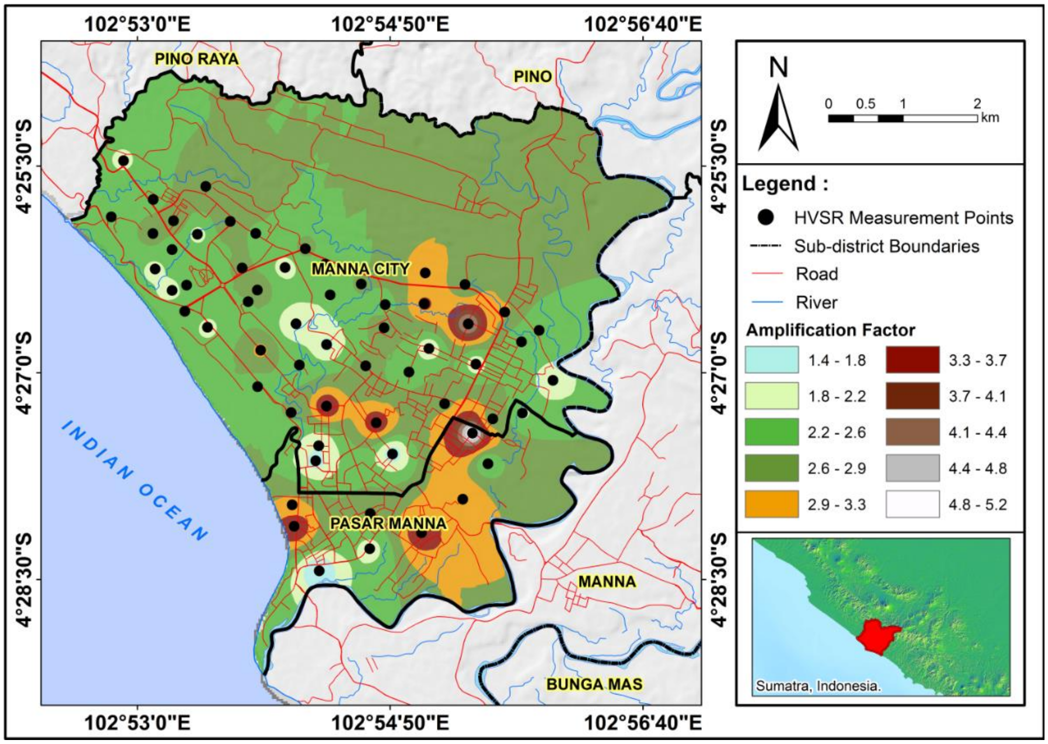

Figure 7. Amplification factor distribution map in the study area overlaid with field data measurement points.

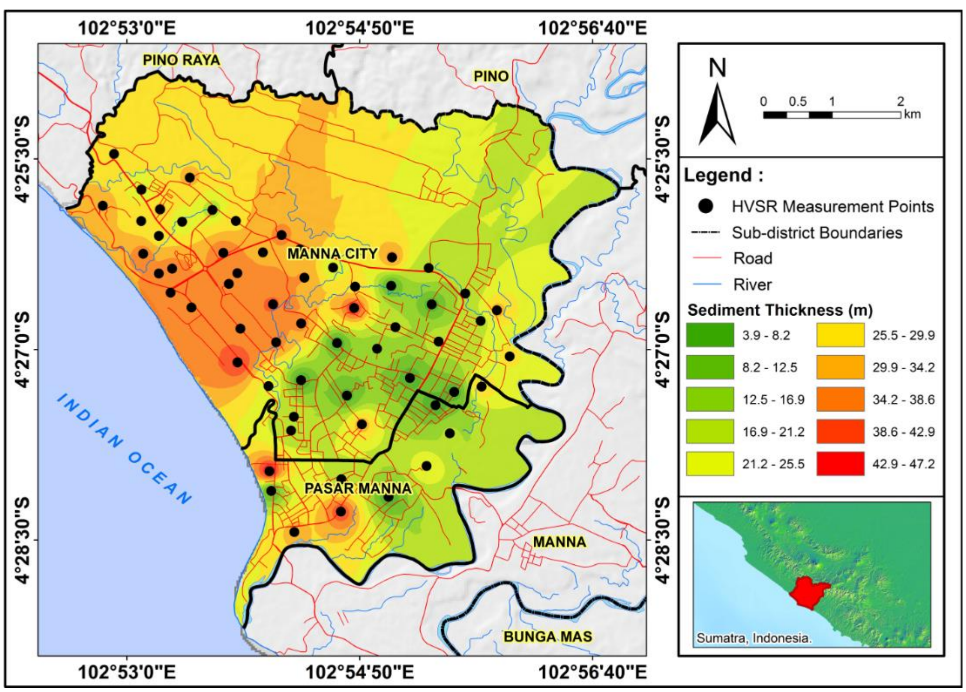

Figure 8. Map of sediment layer thickness distribution in the study area overlaid with field data measurement points.

The sediment layer thickness (h) value reveals that the research region exhibits a range of sediment thickness that ranges from 3.77 to 47.48 meters. This result is based on the computation of the value. Let's have a look at the classification that Kanai and Tanaka developed for classifying the thickness of the sediment layer (h). At this location, the sediment layer thickness (h) can be broken down into four different categories: types I, II, III, and IV [13]. Type I is characterized by a range of sediment layer thicknesses greater than 5 meters and a surface layer thickness that is quite thin. The dark green territory that serves as the boundary between Manna City and Pasar Manna is the primary focus of this kind. Type II has a layer thickness value of 5–10 meters and falls into the medium category; this type is distributed in the northern and eastern portions of the research area, which have a light green coloration.
The sediment layer thickness of Type III ranges from 14.12 to 30.92 meters, placing it in the thick category. This type of sediment layer can be found in the northern part of Manna City and the coastal region of Pasar Manna, and it has a color range from light green to yellow. This sort of sediment, which has a thickness value that ranges from 31.28 to 47.48 meters and is spread along the coastal area of the city of Manna and is colored orange to red, has a thickness value that indicates a very thick layer of sediment. According to the map that depicts the distribution of the layer thickness, the vast majority of the area under study has a layer thickness that ranges from extremely thick to very thick. Layer thickness and dominant frequency value are related to one another in an inversely proportional fashion. The values of the dominant frequency, A_0, are demonstrated to be high in regions that have a low sedimentary layer thickness. On the other hand, regions that have a substantial sediment layer thickness (h) are distinguished by a low dominant frequency (A_0). This is evident from the way the values of the dominant frequency, denoted by "A_0," are distributed in Figure 6. This is due to the fact that the propagation of waves can be slowed down by a medium that possesses soft qualities. Nevertheless, the result is that there is a considerable amount of variation in the vibration. The amplification phenomenon also increases the strength of earthquake vibrations, which have the potential to inflict damage to the surface soil as well as the building structures that are situated above it.

On the basis of the topographic map of the research region that is presented in Figure 5, it is possible to see that zones with high sediment layer thickness have a tendency to appear in low topographic areas, moving westward toward the coast. In the meantime, the low viscosity of the sediment layer may be found in the high terrain that faces southeast and borders the Manna Subdistrict. This demonstrates that there is also a relationship between the topography of the study region and the thickness of the layer.

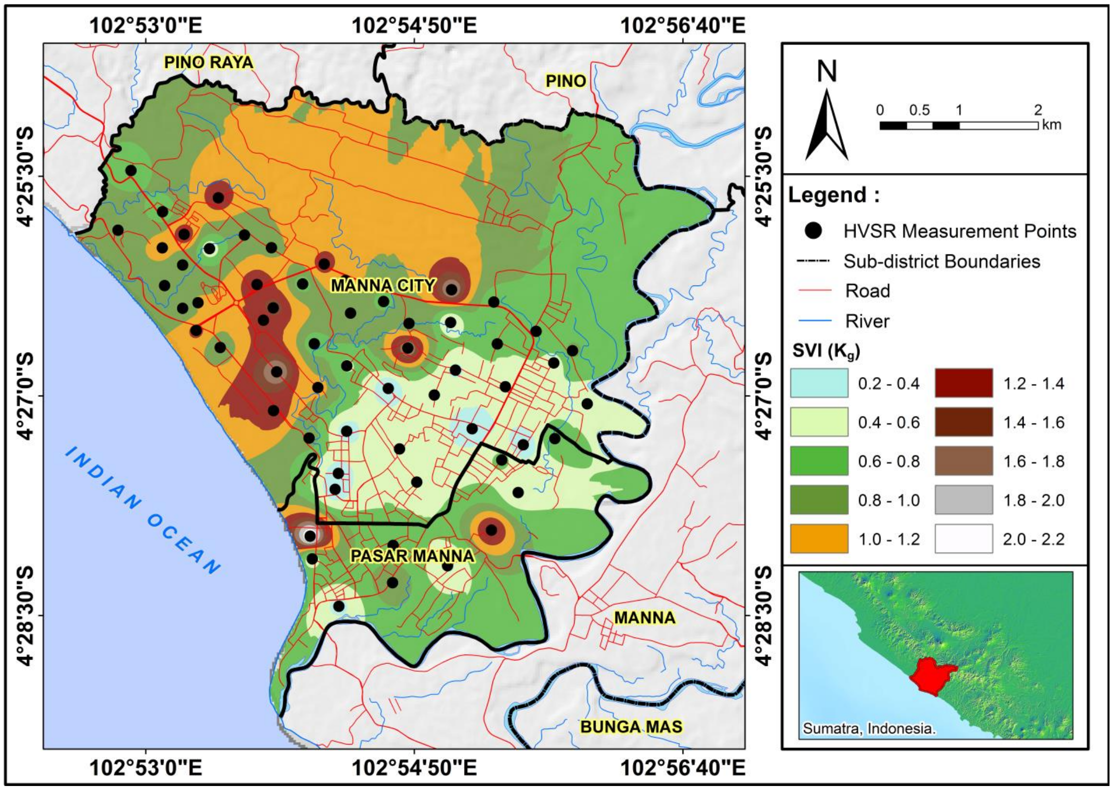

Figure 9. Seismic vulnerability index distribution map in the study area overlaid with field data measurement points.

Based on how easily the soil's surface layer will shake during an earthquake, the seismic vulnerability index, also known as Kg, can determine how likely it is that damage will result. The magnitude of the dominant frequency value (A_0) and the level of amplification (A_0) are both important factors in determining the seismic vulnerability index (K_g). In addition to this, the seismic vulnerability index (K_g) has a relationship that is proportionate to the thickness of the sediment layer (h), which also has a relationship. Imagine that the seismic vulnerability index (K_g) for a certain region has reached a high level. If this is the case, then it is possible to draw the conclusion that the region contains a sediment layer that is a considerable distance thick. On the other hand, a low seismic vulnerability index (K_g) in a region may be an indication that the sediment layer in that region has a tendency to have a thinner layer.

The findings of the calculation of the seismic vulnerability index (K_g) show that the study region shows a low value on the seismic vulnerability index (K_g), which can vary anywhere from 0.18 to 2.24. This can be seen by observing that the seismic vulnerability index (K_g) displays a low value. The results of these computations are presented in the form of a distribution map for the seismic vulnerability index in Figure 9. The seismic risk index is broken up into three distinct categories: the low zone has a K_g value of less than 3, the medium zone has a K_g value between 3 and 6, and the high zone has a K_g value that is greater than 6. On the basis of the seismic vulnerability index map, it can be seen that the research area has a low Kg value, and it is believed to have relatively thin sediments that have a high degree of rigidity [16]. The lower the value of the seismic vulnerability index, the less likely it is for the research region to sustain damage as a result of earthquakes [17].

According to what can be observed on the map of the distribution of the thickness of the sediment layers shown in Figure 8, The sediment layer thicknesses (h) of the majority of the study sites range from moderately thick to extremely thick. On the other hand, the majority of these study regions have low amplification values (A_0) and are composed of rock that is not easily deformed. As can be seen in Figure 7, both the level of the vibration and the potential dangers will be rather low.

Conclusion

The dominant frequency values in the area under study ranged from 3.95 Hz as the lowest value to 49.71 Hz as the highest value, as determined by the outcomes of the data processing performed on the microtremor recording data. In addition, there is a low amplification value, which is 1.43, and a maximal amplification factor, which is 5.19. The seismic vulnerability index ranges from 0.18 to 2.24, with 0.18 being the lowest and 2.24 being the highest. In the area under study, the thickness of the sediment ranges from its thinnest point, which is 3.77 meters, to its thickest point, which is 47.48 meters. The seismic susceptibility index in Manna City and Pasar Manna Subdistricts correlates to the thickness of the sediment layer, and it has a tiny amplification factor, demonstrating the minimal risk and shocks caused by earthquake shaking. Both of these subdistricts are located in the Manna Basin.

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