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ANALYSIS OF MICROTREMOR DATA FOR IDENTIFICATION OF SEDIMENT LAYER THICKNESS BASED ON GROUND PROFILE VS IN SOLOK CITY, WEST SUMATERA

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ABSTRACT

Research has been carried out to analyze the thickness of the sediment layer based on the value of the ground profile Vs (S-wave velocity) from microtremor measurement data sources in Solok City. The thickness of the sediment layer is one of the parameters that affect the amplification or amplification of incoming waves when an earthquake occurs. This study aimed to determine the sediment thickness level in Solok City based on the Vs value in the ground profile model from microtremor data sources. So that the analysis of sediment layers can be used as a form of disaster mitigation caused by tectonic activities such as earthquakes. Single station and array microtremor data were collected, then processed using a combination of HVSR and SPAC methods. The data processing results indicate that the value of S-wave velocity (Vs) derived from microtremor data analysis can be used to determine the thickness of the sediment layer (h), and vs values in Solok City ranged from 126.15-193.35 m/s with depths between 7.23-19.06 m. For areas with unseparated volcanic rock (QTau) lithology, the Vs value is 182.41 m/s. Meanwhile, for areas with geological conditions like alluvium (Qal), the Vs value is 161.66 m/s. The area with a thick layer of sediment, which is 62.74 m, is in the center of the northeastern part of Solok City, covering most of Vi Suku, Nan Balimo, and Javanese Village with alluvium (Qal) lithology and low topography through which rivers flow. Meanwhile, the thin layer of sediment, which is 23.12 m, is located in the western part of Solok City, precisely in Tanah Garam, with undivided volcanic rock lithology (QTau) and high topography in hilly areas.

Keywords: sediment; HVSR; microtremor; solok

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INTRODUCTION

Earthquakes are one of the natural disasters that cause the most significant threats and material losses per unit of time [1]. Earthquakes are caused by collisions between the earth's plates or active faults due to volcanic activity. Researchers are trying to find the correct pattern related to the factors that cause severe damage arising from earthquakes. Some seismologists agree that local geology, especially sediment thickness, has an important effect on seismic motion [2]. The dynamic response of the ground to earthquakes varies widely. Ground motions can be significantly amplified if the geological conditions are unfavorable. This is because the thickness of the sediment layer also affects the amplification of the waves in the area [3]. Therefore, local site effect studies are an important part of solid ground motion events and seismic and seismological hazards in general. The local site effect is the geological conditions in the surface layer which get the effect of ground vibrations during an earthquake [4]. Solok City is an area in West Sumatra prone to earthquakes. This is because geographically, the city of Solok is in an active tectonic condition, which is adjacent to a subduction zone which is the boundary of the Indian-Australian plate with a velocity of 50-60 cm/year and the Eurasian plate with a plate movement velocity of 57 mm/year [5]. In addition, Solok City has a high earthquake vulnerability index because it is passed by the Sumatran fault segment, namely the Sumani and Sianok segments [6]. Meanwhile, the topography of the Solok City area is lowland and high, which are dominated by indivisible volcanic rocks (QTau) and alluvium (Qal), as shown in Figure 1.

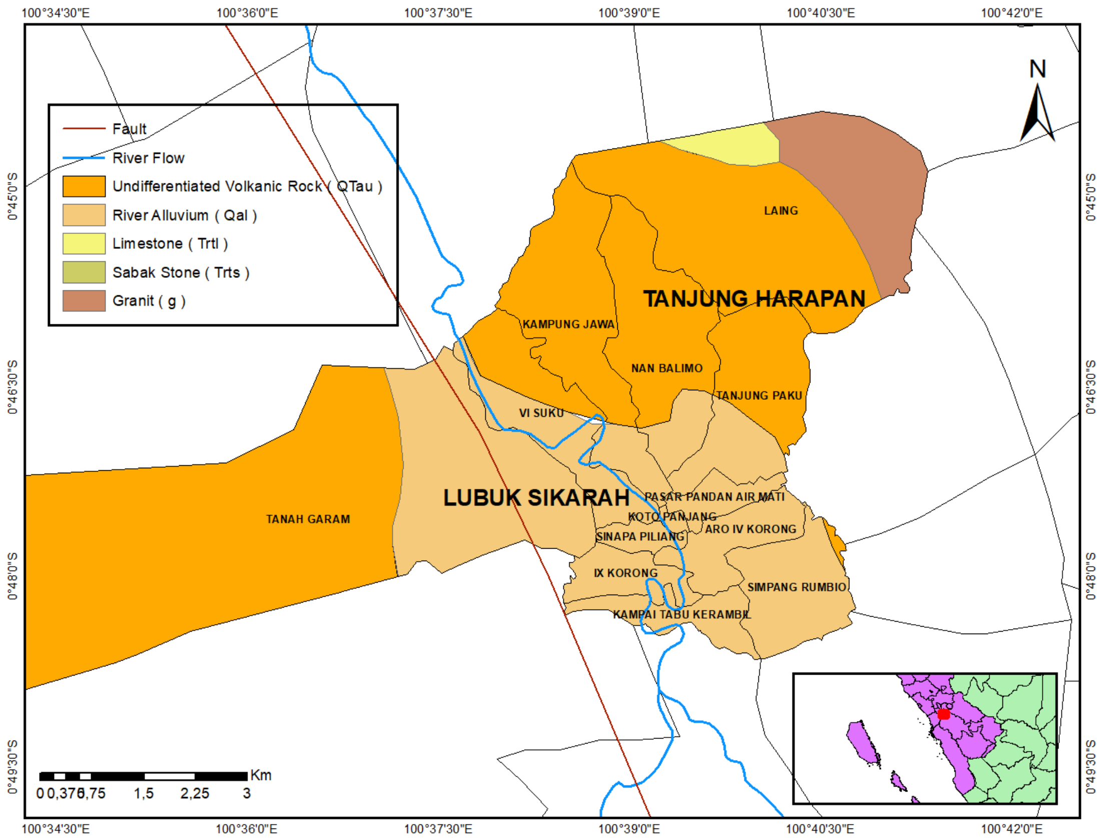

Figure 1. Geological map of solok city (modification from [7])

The geological conditions dominated by soft rocks like this can trigger severe damage if an earthquake occurs because they are caused by the strengthening of waves that propagate from hard rock to soil (alluvium) [8]. To minimize this, this study aims to determine the level of sediment thickness in Solok City based on the Vs value in the ground profile model from microtremor data sources using the single station and array methods which are processed using the HVSR and Spatial Autocorrelation (SPAC) methods. Microtremor is a very small seismic wave originating from various vibrations [9]. Microtremor measurement is popular because it is easy, practical, and cost-effective. Microtremor data will be processed using the HVSR method to produce a dominant frequency value (fo), while processing using the SPAC method will produce a ground profile from the S-wave velocity value (Vs) [10]. Combining these two methods in processing microtremor data related to subsoil structure and site effects produces a reasonable interpretation [11]. However, there is little use of microtremor array data and the SPAC method in microtremor data processing, especially to determine the value of S-wave velocity (Vs), especially in the Solok City area. Previous research in the global area on measuring sediment layers from microtremor data sources has been carried out using the HVSR and SPAC methods [4], [12-15]. Based on the problems above, research is needed on the analysis of sediment layer thickness based on ground profile Vs values from microtremor measurement data sources in Solok City as a form of mitigation of hazards caused by earthquakes.

METHOD

Tools and Materials

The research location is in Solok City, West Sumatra province, to be exact at the coordinates 0°44'28"- 0°49'12" South Latitude and 100°32'42"- 100°41'12" East Longitude with an area of 57 .64 km². This research was conducted in 2015. The number of measurement points is 94, consisting of 8 array measurement points and 86 measurement data points in single stations, shown in Figure 2.

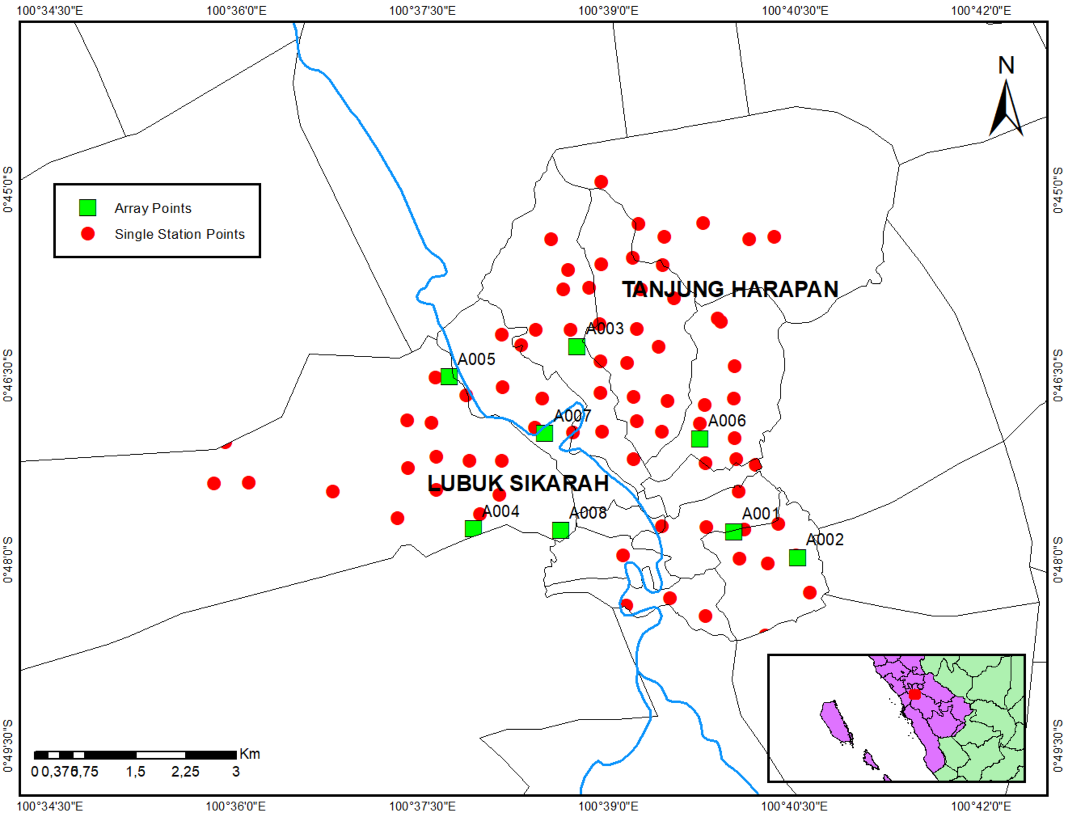

Figure 2. Measuring points for retrieval of microtremor data

Tools used in data measurement single station is a Mark L4-3D type seismometer with a response frequency of 1-100 Hz, while the microtremor array measurement data use a seismometer type OYO model 1134. The recording duration in this study ranges from 13-200 minutes. After getting the single station and array data, do the data processing to get the dominant frequency (fo) value and S-wave velocity (Vs). Both data are then analyzed to obtain the thickness of the sediment layer (h). Measurement data from single station microtremor were analyzed using the HVSR method with the help of Geopsy software to determine the value of the dominant frequency (fo). The dominant frequency is the frequency value that often appears or the frequency value of the rock layers so that the frequency value can indicate the type and characteristics of the rock [16]. The dominant frequency value is related to the depth of the reflected field for subsurface waves. Because the spectral ratio between the horizontal and vertical components in bedrock is close to unity, there is only an effect caused by the local site effect [17-18]. The dominant frequency value obtained from the analysis of the wave spectrum processed by the HVSR method is shown in Figure 3.

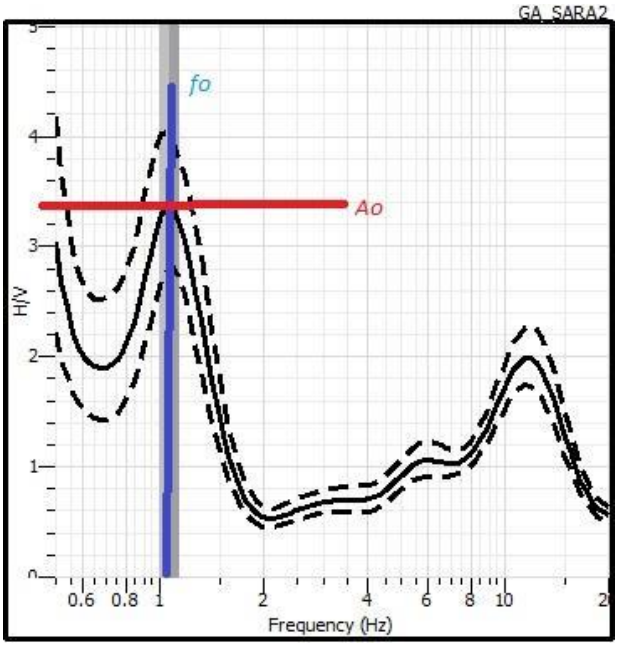

Figure 3. HVSR curve

The microtremor array measurement data was processed using the SPAC method (Spatial Autocorrelation) to determine the S-wave velocity (Vs). The SPAC method survey was carried out with a configuration made in a triangular shape to obtain a dispersion curve [19]. The size of the triangular array is designed according to the target depth required. Measurements at one observation location were performed by installing four sensors in each triangular array, where one sensor was placed in the circle's center and three sensors spread outside the circle. Data processing begins with the Geopsy program, the Spac2disp subprogram, and the Dinver subprogram. The SPAC method is carried out by transforming the time domain microtremor data into the frequency domain for all sensor arrays and then calculating the correlation of microtremor data for each pair of sensors [14]. This method bases its theoretical foundation on the prerequisites of a stochastic wave field which is stationary in time and space [20]. It is shown that with this assumption, the relationship that exists between the density spectra in space and time can be used to derive the following equation [21].

$$\bar{\rho}(r,\omega) = J_o\left(\frac{\omega r}{c\,(\omega)}\right) \tag{1}$$

With $\bar{\rho}(r,\omega) = \int_0^{\pi} \rho(r,\omega,\theta)\, d\theta$ represents the azimuth means spatial autocorrelation *Jo* = Bessel function of zero order of the first kind, *c(ω)* = phase velocity as a function of frequency *ω, r* = distance between two stations. The S-wave velocity profile is obtained from the inversion process, which is carried out by matching the theoretical coherence curve of the Bessel function to the measurement coherence curve $\bar{\rho}(r,\omega)$ [21].The calculation of the Vs value is obtained from the analysis ground profile in the Diver program. Ground profile obtained based on the Rayleigh wave dispersion matrix equation, which is inverted using the global minimum inversion method neighborhood algorithm [16].

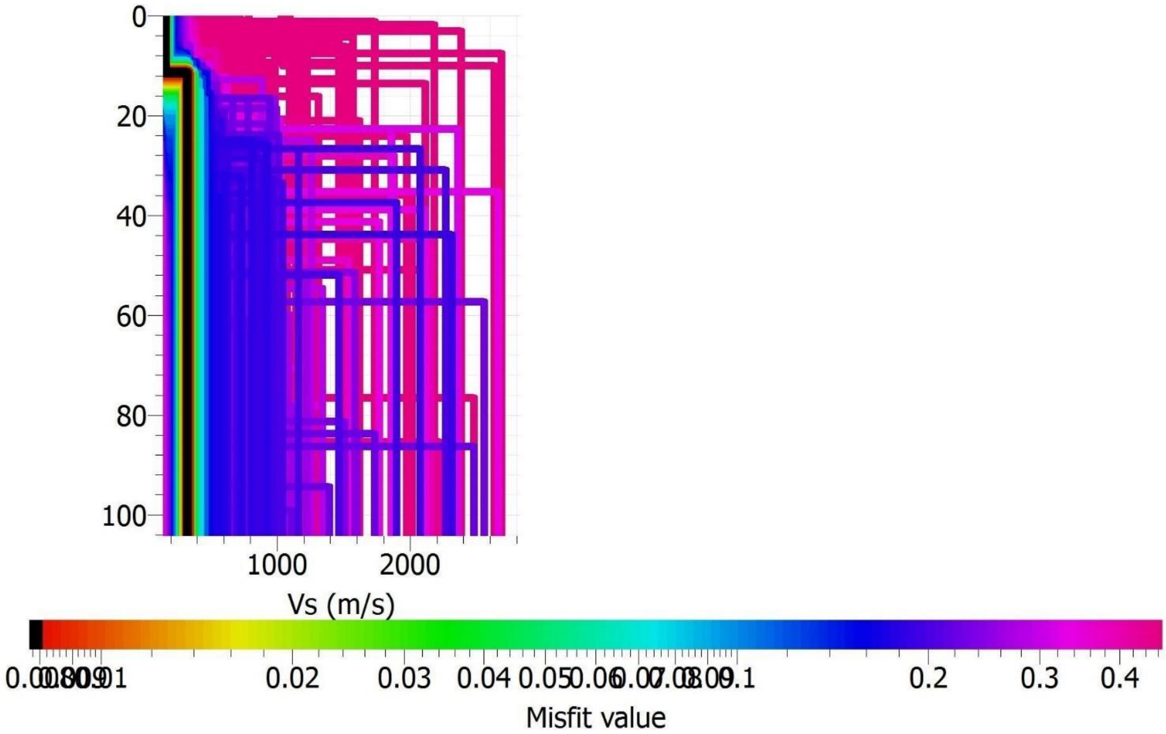

Figure 4. Display of inversion results ground profile in the dinver program

After getting the Vs value from the SPAC method analysis, we can calculate the value of the thickness of the surface sediment layer using Equation (3). It is essential to know the velocity of shear wave propagation (Vs) in an area because Vs provides information on whether the expected earthquake vibration response in a layer of soil has the potential to be higher so that it can cause damage. When the sediment layer thickness (h) is λ/4, the amplification is maximum at a specific frequency called the resonant frequency. λ is the second wavelength in meters [22].

$$\lambda = \frac{V_S}{f} \quad (2)$$

Natural frequency influences the thickness of the sediment layer, where the natural frequency is best proportional to the thickness of the sediment layer. The greater the natural frequency, the smaller the thickness of the sediment layer. And conversely, the smaller the natural frequency, the greater the thickness of the sediment layer. This is because the dominant period of seismic waves in an area is directly proportional to the thickness of the sediment layer [23]. Mathematically the thickness of the sediment layer can be written as follows [24]:

$$f_0 = \frac{V_S}{4 \times h}$$

$$h = \frac{V_S}{4 f_o} \quad (3)$$

Research [15-16, 19] states that Equation (3) can be used to determine the thickness of the sediment layer properly.

RESULTS AND DISCUSSION

Discussion of S-wave velocity is critical to determine the local site effect [15, 25-26]. Microtremor array measurements are used to calculate the thickness of the sediment layer and S-wave velocity in the sediment layer using the SPAC method (Figure 5).

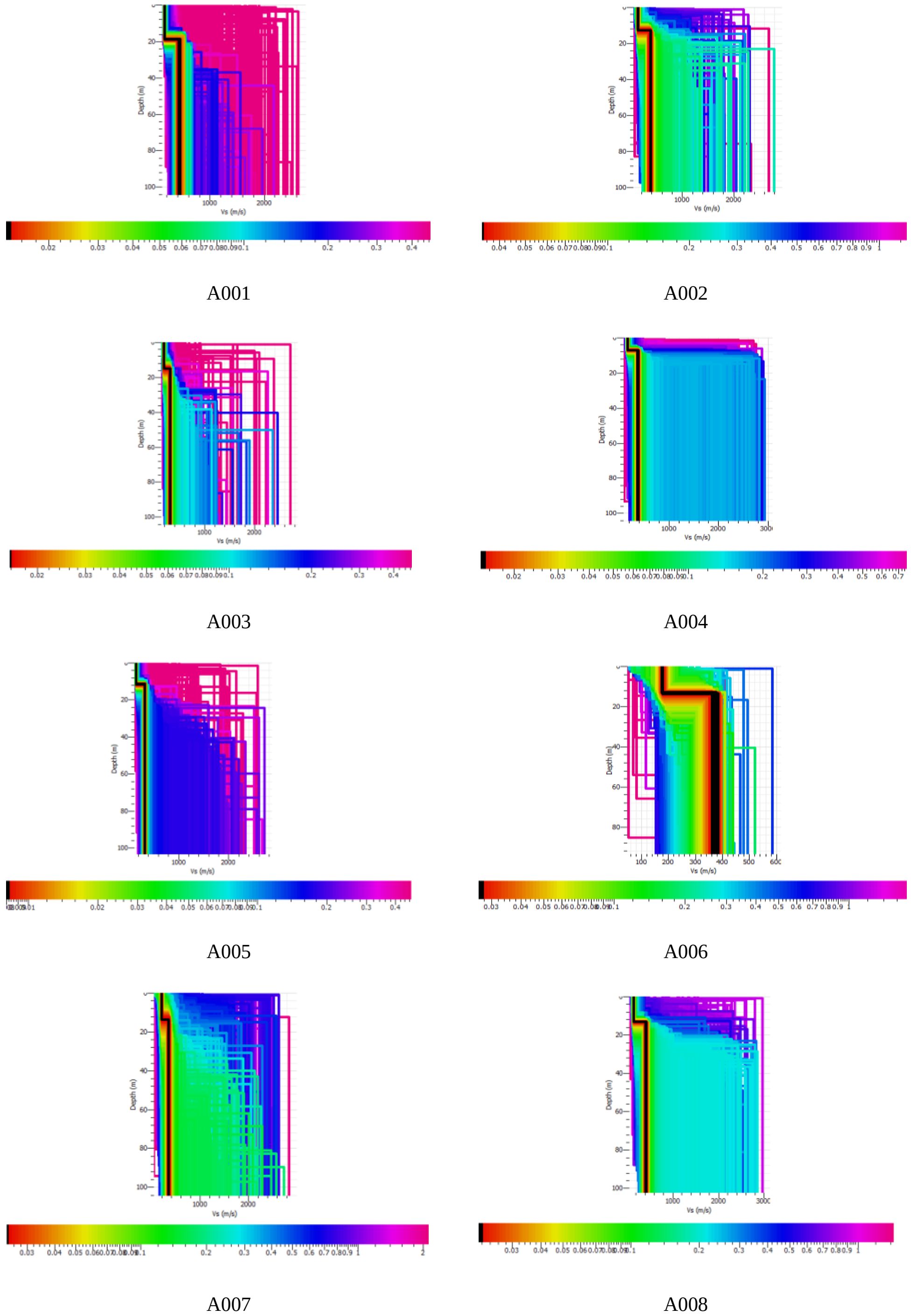

Figure 5. Display of ground profile inversion results in the dinver program.

S-wave velocity(Vs) and sediment layer thickness (H) based on SPAC dispersion curve analysis can be seen in Table 1.

Table 1. S-wave velocity (Vs) and sediment layer thickness (H) from SPAC analysis

Measuring Point	Vs (m/s)	H (m)	Rock Type (based on geological maps)
A001	150.82	19.06	Qal
A002	126.15	12.88	Qal
A003	182.41	14.78	QTau
A004	167	7.23	Qal
A005	162.59	11.06	Qal
A006	177.24	13.25	Qal
A007	193.35	13.8	Qal
A008	154.53	13.21	Qal

The analysis using the SPAC method at eight measurement points obtained S-wave velocity values in the sediment layer ranging from 126.15-193.35 m/s with depths between 7.23-19.06 m, as seen in Figure 2. Sediment layer thickness values from the SPAC dispersion curve analysis are not considered because the assumption of homogeneous sediment layers in the inversion of the dispersion curve causes inaccuracy in determining the depth. However, the S-wave velocityvalues in the sediment layer are very close to the average S-wave velocityvalues from measurements in the borehole [27]. The results for the distribution of S-wave velocity values (Vs) can be seen in the Figure 6.

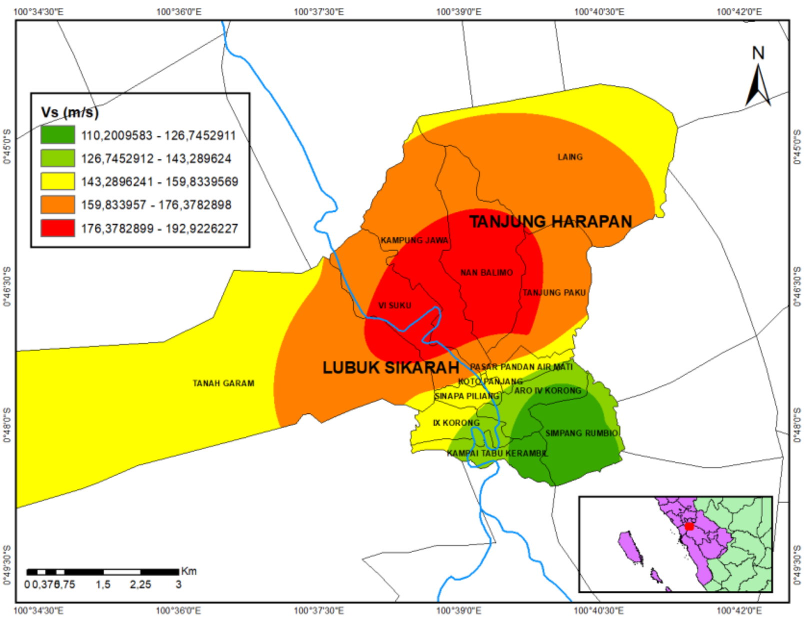

Figure 6. Distribution map of S-wave velocity (Vs) values.

The highest S-wave velocity value is in the central area of Solok City, which is marked with a red area. his S-wave velocity value is adjusted to the geological information of the study area (Figure 1) which is adjusted to the point of measurement and then the results are averaged. The average Vs value is used to map the thickness of the sediment using Equation (4). For areas with geological conditions in the form of unseparated volcanic rocks (QTau), namely colluvium, conglomerate, and lava deposits, the S-wave velocity value is 182.41 m/s.

Meanwhile, for areas with geological conditions in the form of alluvium (Qal), the average S-wave velocity value is 161.66 m/s. The S-wave velocity value is then used to determine the thickness of the sediment layer at each measurement point. The dominant frequency value also influences the determination of the sediment layer. In addition to being influenced by the S-wave velocity (Vs), the determination of the sediment layer is also influenced by the value of the dominant frequency (fo), which can be classified based on the soil type, as shown in Table 2 below.

Table 2. Soil classification based on dominant frequency value by Kanai[28].

Dominant Frequency (Hz)	Classification	Description
6,667 – 20	Tertiary or older rocks. It consists of hard sandy rocks, gravel, etc.	The thickness of surface sediment is skinny and dominated by hard rock.
10 – 4	Alluvial rock, 5m thick. Consists of sandy gravel, sandy hard clay, loam, etc.	The thickness of the surface sediment is in the medium category of 5-10 meters.
2,5 – 4	Alluvial rock, > 5 m thick. Consists of sandy gravel, sandy hard clay, loam, etc.	The thickness of the surface sediment is in the thick category, around 10-30 meters
< 2,5	Alluvial rock is formed from delta sedimentation, topsoil, mud, etc.	With a depth of 30 m or more, the thickness of the surface sediments is very thick.

The dominant frequency value is determined from the microtremor data single station. The data is then analyzed using the HVSR method with Geopsy software to obtain the wave spectrum. From the spectrum of these waves will get the HVSR curve which shows the dominant frequency value. In this study, the dominant frequency value is shown in Figure 7.

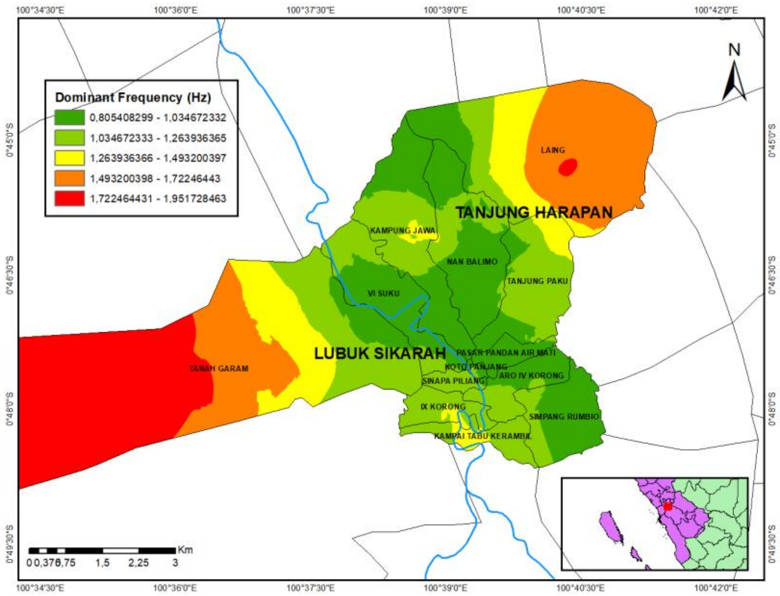

Figure 7. Distribution map of dominant frequency values.

The dominant frequency value of the soil in the study area ranges from 0.8-1.9 Hz. Figure 7 above shows that the smallest dominant frequency value is indicated by green interpolation, while the red color indicates the most considerable dominant frequency value. The lithology of the constituent rocks influences the size of the dominant frequency value. In this study, the smallest dominant frequency value has the highest S-wave velocity in the middle of Solok City with regional morphology in the form of lowlands through which rivers pass (Figure 8).

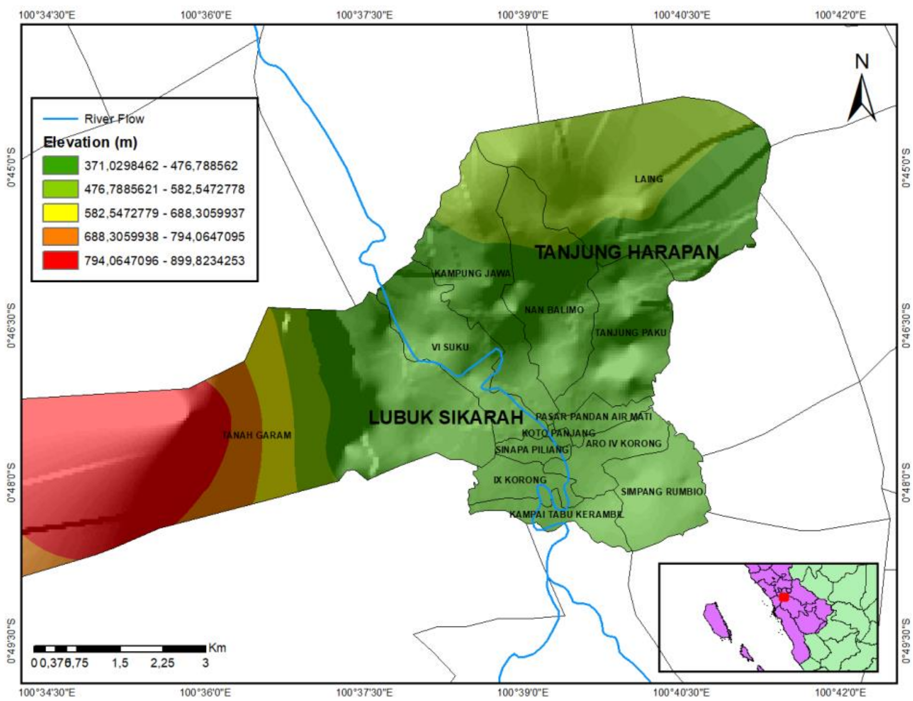

Figure 8. Topographic map of the study area.

From the topographic map of the study area, the central area of Solok City is a lowland (green color) with an elevation of 371 m. In comparison, the western area of Solok City is a highland (red color) consisting of hills with an elevation of 899 m. Based on the suitability of the dominant frequency distribution values with soil classification based on Table 2 and the geological map (Figure 1), most of Solok City is dominated by alluvium rock formed from river sedimentation and very thick mud. Based on the Vs and fo values, the thickness of the sediment layer can be calculated using Equation (3), and the results are shown in Figure 9.

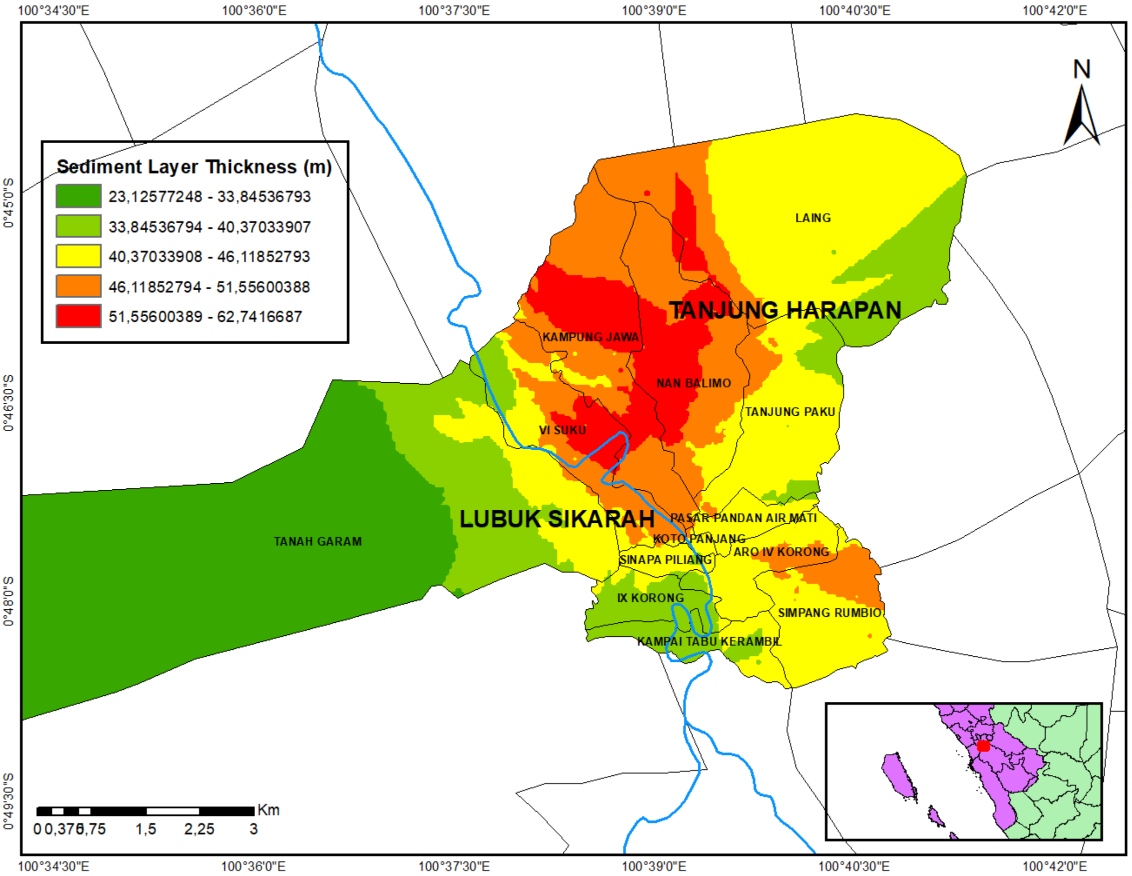

Figure 9. Sediment layer thickness map

Based on the map above, the area with the thickest sediment is central to the northeastern part of Solok City, including most of Vi Suku, Nan Balimo, and Javanese Village, which has a low elevation with a sediment thickness of 62.74 m. At the same time, the area with the thinnest sediment is in the western part of Solok City, precisely in Tanah Garam, at a higher elevation with a sediment layer thickness of 23.12 m. Based on the geological map of the study area (Figure 1), areas with thick sedimentary layers are dominated by alluvium (Qal) rock types. Meanwhile, areas with thin sediment layers are dominated by unseparated volcanic rocks (QTau). Sedimentary layers are soft rocks composed of the deposition of sedimentary rocks composed of one another. A thick layer of sediment with a large sediment density will make the frequency value small but increase the wave amplitude value. In addition, the thicker the sediment layer, the greater the S-wave velocity [29].

The distribution value of this sediment thickness does not correspond to the elevation level of the study area, where the highest sediment thickness values are in areas with low elevation values through which the river flows, while the smallest sediment thickness values are in areas with high elevation values. Bedrock morphology in the study area can be determined by subtracting the surface elevation at the measurement point from the thickness of the sediment layer. The values obtained were then interpolated to obtain an overview of bedrock morphology. The composition of the layers that make up the lithology of the Solok City area can be described according to Figure 10.

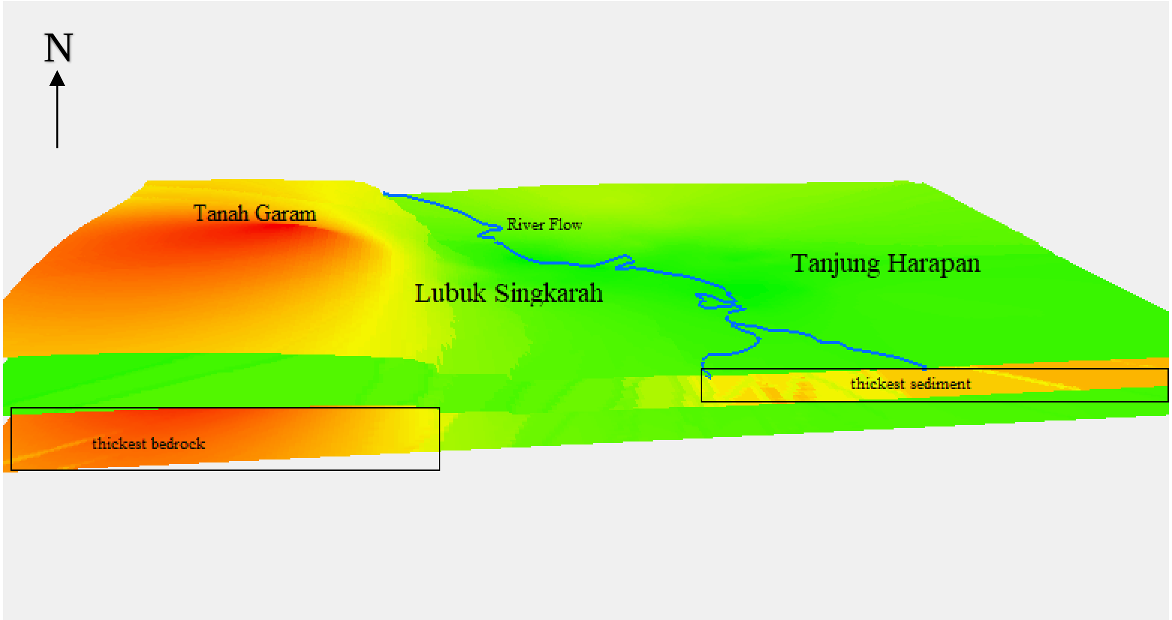

Figure 10. Sediment layer thickness map

The arrangement of the lithological layers consists of sediments and bedrock. The area with high elevation is in the western area. Meanwhile, the central to eastern areas are dominated by thick sediments. The thick bedrock area is in the high elevation area, namely the western area. In general, variations in sediment thickness values have relatively the same pattern as the geological characteristics of the study area. In addition, it is also influenced by topographical factors and variations in shear wave velocity in the study area.

CONCLUSION

S-wave velocity values (Vs) derived from microtremor data analysis can be used to determine the thickness of the sediment layer (h), and vs values in Solok City ranged from 126.15-193.35 m/s with depths between 7.23-19.06 m. For areas with unseparated volcanic rock (QTau) lithology, the Vs value is 182.41 m/s. Meanwhile, for areas with geological conditions like alluvium (Qal), the Vs value is 161.66 m/s. The area with a thick layer of sediment, which is 62.74 m, is in the center of the northeastern part of Solok City, covering most of Vi Suku, Nan Balimo, and Kampung Jawa. With alluvium lithology (Qal) and low topography through which rivers flow. Meanwhile, the thin layer of sediment, which is 23.12 m, is located in the western part of Solok City, precisely in Tanah Garam, with undivided volcanic rock lithology (QTau) and high topography in hilly areas.

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