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Empirical Equation between Predominant Frequency and Sediment Thickness in Plampang, West Nusa Tenggara

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ABSTRACT

Soil characteristics mapping is one of the essential aspects in the development of a region. Soil characteristics such as the predominant frequency and thickness of the sediment layer are needed to ensure the capacity of soil against the load of an infrastructure construction. The existence of tectonic activity causes West Nusa Tenggara Province to be an area with high seismic activity. Along with the plan to accelerate the development of the Samota Area, seismic studies are one of the aspects that determine project feasibility. The predominant frequency value from the results of microtremor measurements is used in the development of an empirical formula to predict soil thickness in the Plampang area. The empirical formula from previous research is used as a conformity test of the empirical formula obtained. Empirical equations are then used to map variations in sediment thickness in the Plampang area, which are justified based on geological data. The results of the sediment thickness map based on the empirical formula for the Plampang area showed a good correlation with the predominant frequency and also showed a good correlation with the results of the formula that has been carried out by previous studies.

Keywords: sediment thickness, empirical formula, microtremor

INTRODUCTION

Geologically, Indonesia is located between 3 major plates, the Eurasian, Pacific, and Indo-Australian plates. Constructed on a combination of various continental plates and volcanic arcs, Indonesia is often experience earthquakes [1]. This earthquake caused a lot of infrastructure damage that could result in death. Furthermore, secondary effects due to earthquakes, such as tsunamis and liquefaction, contribute to the amount of damage and casualties. In Indonesia, hundreds of people became victims of earthquakes that occurred in various regions, including the Aceh, Papua, Yogyakarta, Ambon, Sumbawa, Flores, and Padang earthquakes.

In line with the development of the Samota Area, namely Saleh, Moyo, and Tambora Bays on Sumbawa Island, West Nusa Tenggara (NTB), mapping an area based on soil characteristics is an important aspect to be done. Mapping the thickness of the sediment layer is necessary to ensure the service capacity of soil against construction loads to be built, such as houses, office buildings, roads, and bridges. Apart from that, mapping an area will minimize damage to infrastructure caused by vibrations from earthquakes, especially in buildings that are designed to be earthquake-resistant.

In addition to the earthquake magnitude and distance to the source, infrastructure damage is also affected by subsurface conditions [2]. Waves that propagate through a soft medium will have a greater effect than on a harder medium, even though the source and magnitude of the earthquake are the same. Seismic waves passing through layers of soft sediments at low speed may experience several phenomena, including amplitude increases, wave paths bend, and waves get trapped in layers near the surface [3]. Seismic energy is trapped due to the impedance contrast between the soft soil and the underlying bedrock [4].

This phenomenon causes soft lithology to have a higher risk when an earthquake occurs because it increases ground shaking, which causes structural damage. Various conventional techniques have been developed to calculate bearing capacity related to soil characteristics and thickness, such as the Standard Penetration Test (SPT) and Cone Penetration Test (CPT). Soil characteristics can also be obtained through the application of active geophysical techniques as they are well known, such as refraction seismic, refraction seismic, and geotechnical drilling. However, these methods require significant costs and time to implement. On the other hand, a passive geophysical technique known as microtremor measurement has been successfully used in investigations with less cost and time.

Microtremor measurements and calculations of the predominant frequencies were carried out based on the maximum H/V spectral values. This method measures the ratio between the horizontal and vertical components of noise. In general, the horizontal component of microtremor measurements shows a higher peak than the vertical component. The contrasting difference between the two components is caused by the presence of contact between the soil and bedrock. So that the peak of the horizontal to vertical spectral ratio (HVSR) from microtremor measurements is considered as a frequency according to the predominant frequency of the soil. Meanwhile, the shear wave measurement was carried out using the Spatial Auto Correlation (SPAC) microtremor measurement. The dispersion curve from the SPAC processing results is then inverted to obtain shear waves and the thickness of the sediment layer. The purpose of this research is to develop an empirical equation between the predominant frequency and the thickness of the sediment layers, especially in the Plampang area, Sumbawa Island, West Nusa Tenggara.

Geological Setting and Seismicity

Sumbawa Island is composed of dozens of rock units that are quite complex, including intrusion rocks, old volcanic rocks, Miocene Penggulung Formation (consisting of lava and tuff sandstone), limestone units, Late Miocene Kawangan Formation (consisting of tuff breccias), volcanic rock, dacitic tuff, layered limestone, tuff limestone, Late Miocene Ekas Formation (consisting of calcarenite limestone and crystalline limestone), tuff clay, red soil volcanic products, old volcanic products and coral while the top is the youngest layer alluvial.

Based on the geological map, the rocks in the Plampang area are composed of the Alluvium and Coastal Deposits (Qal), and the Volcanic unit (Tmv), as shown in Figure 1. The Alluvium and Coastal Deposits (Qal) are composed of gravel, sand, clay, silt, and sand, mainly composed of andesite and locally containing magnetite. The Volcanic unit (Tmv) is composed of andesitic breccia with local pumice tuff and tuff sandstone inserts containing lava, andesitic lava, and basalt. Generally, the volcanic unit is gray and green in color, the localized lava has a pillow structure interspersed with cherts. Local rock units are propylitized, mineralized, and eroded, with visible veins of quartz and calcite. This volcanic unit was formed in Miocene [5].

Seismically, the Nusa Tenggara Islands are bounded by Java to the west, the Flores Sea to the north, the Banda Arc to the east, and the Indian Ocean to the south. The Nusa Tenggara region is divided into two provinces, namely West Nusa Tenggara (NTB) and East Nusa Tenggara (NTT). Tectonically, NTB is part of the eastern Sunda Arc, which has the characteristics of subduction of tectonic plates, volcanic arcs, and subduction pathways [6].

NTB has earthquake-prone locations spread across the islands of Lombok and Sumbawa [7]. NTB is flanked by two earthquake sources, the subduction of the Indo-Australian plate in the south and the back-arc thrust in the north [8]–[10]. Other sources of earthquakes scattered throughout the Bali-Nusa Tenggara and Banda regions, such as thrust faults behind the island arc and in front of the arc, as well as horizontal faults trending north-south to northeast-southwest, are shown in Figure 2. West Nusa Tenggara become an area with quite high seismicity from both shallow and deep earthquakes [8], [9].

Based on analysis of regional geological and seismotectonic data, data on the distribution of earthquake centers in the Plampang area, does not indicate a surface fault. However, an earthquake of magnitude IV on the MMI scale on August 19th, 2018, caused two houses in the Plampang district to experience wall cracks [11]. It indicated that sediment layer might be a factor that causing amplification of earthquake wave.

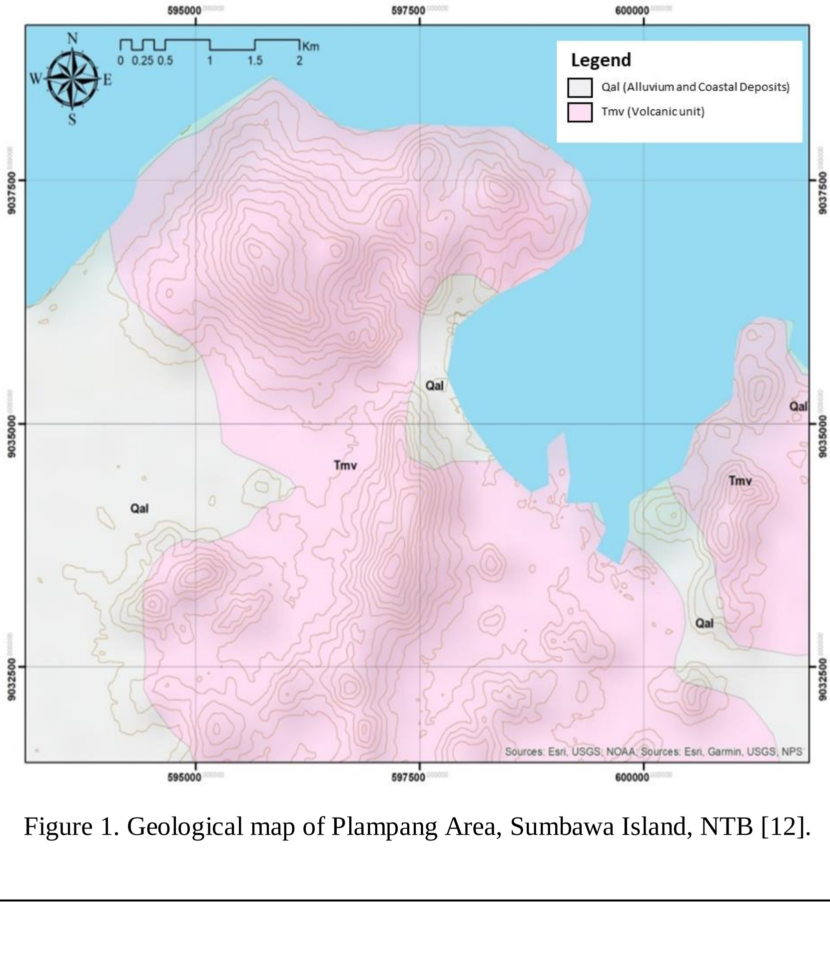

Figure 1. Geological map of Plampang Area, Sumbawa Island, NTB [12].

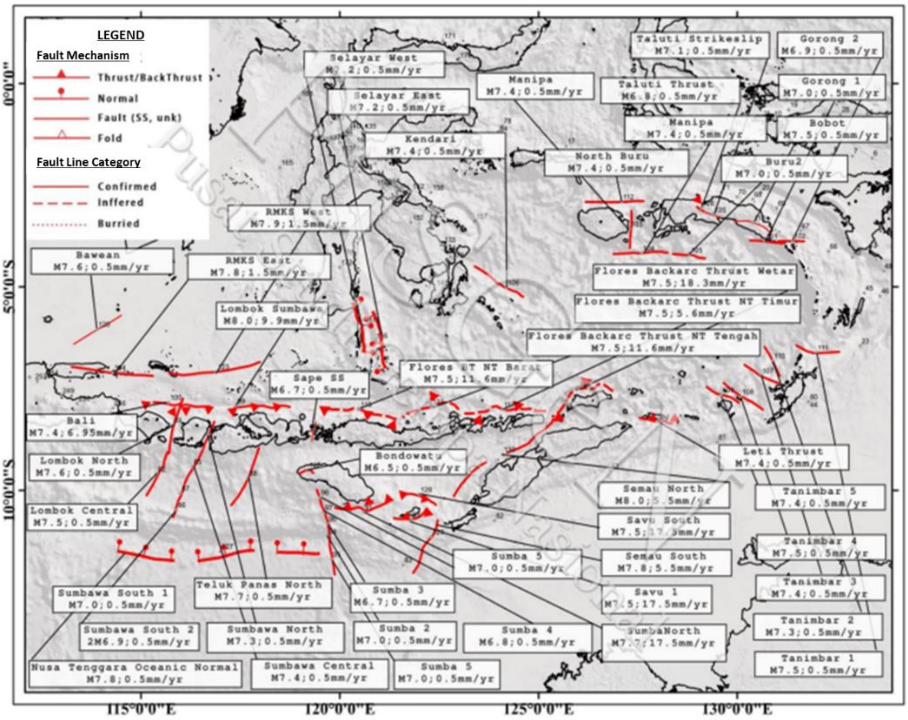

Figure 2. Earthquake Sources in Bali, Nusa Tenggara, and Laut Banda [13].

METHODOLOGY

Microtremor Data Acquisition

Microtremor data was collected using a portable accelerometer McSeis MT Neo as much as one triaxial (2 NS-EW horizontal components and 1 vertical component). Measurements were made at 16 points spread to the north of Plampang, as can be seen in Figure 3 [14].

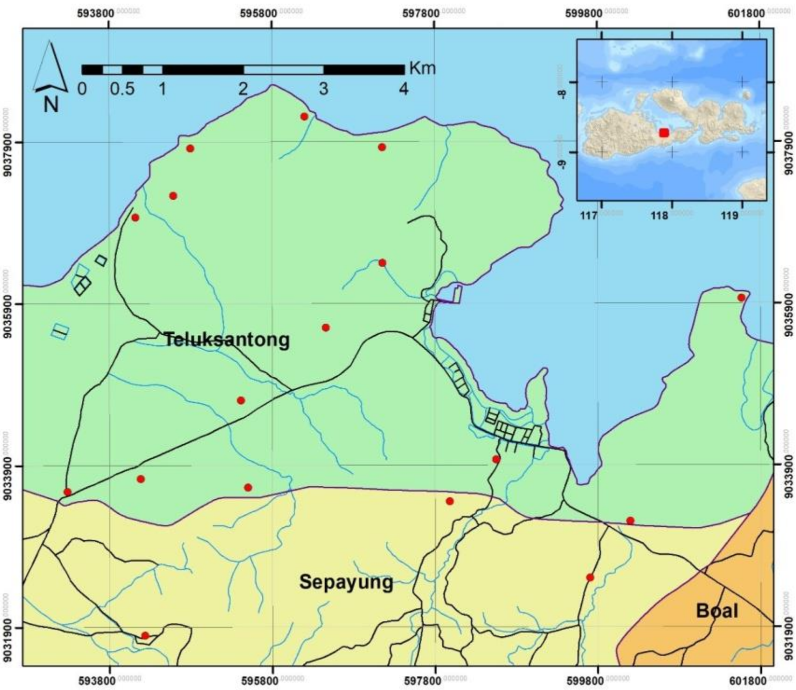

Figure 3. Location Map of Microtremor Measurement in Plampang Area [15].

The measurement duration for each point ranges from 15 to 30 minutes with a sampling interval of 0.01 seconds [15]. Measurements are also carried out by taking into account several important things, such as avoiding measurements during rainy and windy weather conditions and avoiding measurements near to a vehicle with an engine that causes vibration.

Microtremor Data Processing and Analysis

The data from the microtremor survey is in the form of ground vibrations as a function of time. The data is converted using SeisImager so that it can be opened in Geopsy as software for HVSR analysis. The principle of this method is a comparison between the horizontal component Fourier spectrum (east-west and north-south) with the vertical component [14], [16]. The shear wave velocity was obtained from the SPAC microtremor analysis.

The windowing process is carried out with a window duration of 25 seconds. The selected window is only on stationary data and avoids transient noise. The frequency range used ranges from 0.5-25 Hz. Fourier spectrum analysis is performed in each window to convert the time domain into frequency. Then, smoothing is applied using the Konno-Ohmachi method shown in equation (1) with a bandwidth coefficient of 40. The two horizontal components are averaged using the square root mean, and then the H/V ratio is calculated.

$$W(f) = \left[\frac{sin\left(log_{10}\left(\frac{f}{fc}\right)^{b}\right)}{log_{10}\left(\frac{f}{fc}\right)^{b}}\right]^{4} \qquad (1)$$

Where fc is the center frequency, f is the weighted frequency, and b is the bandwidth coefficient, which is a factor that can be controlled in the smoothing process. This value has significant effect on the smoothing results.

Empirical Equation between Predominant Frequency and Sediment Thickness

The predominant frequency is closely related to the thickness of the sediment, as written in the following equation:

$$f_0 = \frac{V_S}{4h} \qquad (2)$$

Where Vs is the average shear wave velocity of the sediment layer above the bedrock, and h is the thickness of the sediment above the bedrock. Nakamura indicated that the predominant frequency can be determined from a comparison of the horizontal spectral $S(\omega)_{NS}$ and $S(\omega)_{EW}$, and vertical spectral $S(\omega)_V$ of ambient seismic noise, where ω is the corner frequency. The H/V spectral ratio can be estimated by the following equation approach:

$$H/V\,(\omega) = \{[S^2(\omega)_{NS} + S^2(\omega)_{EW}]/2S^2(\omega)_v\}^{1/2} \qquad (3)$$

However, this method requires a strong impedance contrast between the bedrock and sediment layers. Conversely, this method will not be effective for areas that do not use these assumptions.

For the first time this research was conducted by Seht and Wohlenberg (1999) [17], it was stated that the thickness of the sediment layer (h) can be obtained using the predominant frequency (f_0) through the following equation:

$$h = af_0^b \qquad (4)$$

With the magnitude of parameters, a and b, respectively 96 and -1.388. Equation (5) can be written as follows:

$$h = 96f_0^{-1,388} \qquad (5)$$

Several other studies on the equation between the predominant frequency and the thickness of the sediment layer have also been published by some researchers. The following are empirical equations presented by Delgado et al. [18], Biswas et al. [19], Monaco et al. [20], Sarfraz Khan and Asif Khan [21] and Suharno et al. [20] respectively

$$h = 55{,}64 f_0^{-1{,}268} \quad (6)$$

$$h = 160 f_0^{-1{,}459} \quad (7)$$

$$h = 129{,}3 f_0^{-1{,}06} \quad (8)$$

$$h = 134 f_0^{-1{,}23} \quad (9)$$

$$h = 20{,}129 f_0^{-2{,}151} \quad (10)$$

RESULTS AND DISCUSSION

The predominant frequency value is a reflection of the thickness of the sediment. A high f_0 value indicates a thinner sediment thickness or rock outcrops on the surface, and vice versa, a low value indicates that the area has a greater sediment thickness. The predominant frequency (f_0) value in the study area ranges from 0.6 Hz to 22.2 Hz. Based on the distribution of predominant frequency values (Figure 4), the northern and southwestern parts of the study area (light green color) have rocks with a thinner sediment layer thickness compared to other areas where several rock outcrops are found on the surface [12]. The distribution of these predominant frequency values corresponds to the topography of the study area, where high values to the north indicate areas with higher elevations.

Based on the geological map, most of the high predominant frequencies are in tuff-breccia units. There are only a few alluvial deposits and coastal deposits that have a relatively high frequency, indicating that this area has a thin layer of sediment. The lowest frequency value is located on the southeast area that dominantly composed by breccia and tuff. Although, it is composed of breccia and tuff, it is possible that the area contains thick alluvium deposits that are continuous from alluvium deposits to the east.

Figure 4 shows the distribution of predominant frequencies in the Plampang area. In general, the predominant frequency values in the research area have relatively high values, reflecting that the rock conditions are massive and stable. According to the value of predominant frequencies, the research area, especially in the north and southwest, is relatively safe from from potential local site effects due to earthquakes.

The empirical equation between the predominant frequency and the thickness of the sediment layer shows a negative nonlinear pattern relationship. Several previous studies have been carried out on the prediction of empirical equations based on geotechnical drill data. Then other researchers also did it at different locations. The predominant frequency that has been obtained from the HVSR calculation and the thickness of the sediment layer from the results of the SPAC microtremor analysis is plotted on the graph then the fitting curve model is obtained based on equation 4 and can be written as follows:

$$h = 42.593 f_0^{-0{,}903} \quad (11)$$

This equation is applicable, with the value of R^2 is 0.997. Then, the compatibility between equation 11 and the equations from previous studies is plotted together, as shown in Figure 5, and shows a strong correlation relationship. This can be seen from the pattern of fitting curves that fall within the limits. The thickness of the sediment layer in the Plampang area are ranging from 2.9 to 97.7 m (Figure 6). The thickness of the sediment layer from the results of empirical equation calculations shows that the

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southeastern side of the study area is composed of a layer of sediment with a fairly large thickness. This condition is consistent with the geological map, where the southeast side is composed of alluvium (Qal) which composed of silt and sand. Meanwhile, the north side of the study area has a layer of sediment with a fairly thin thickness. Based on the geological map, the north side is composed of breccia-tuff units. In addition, outcrops were also found in several locations.

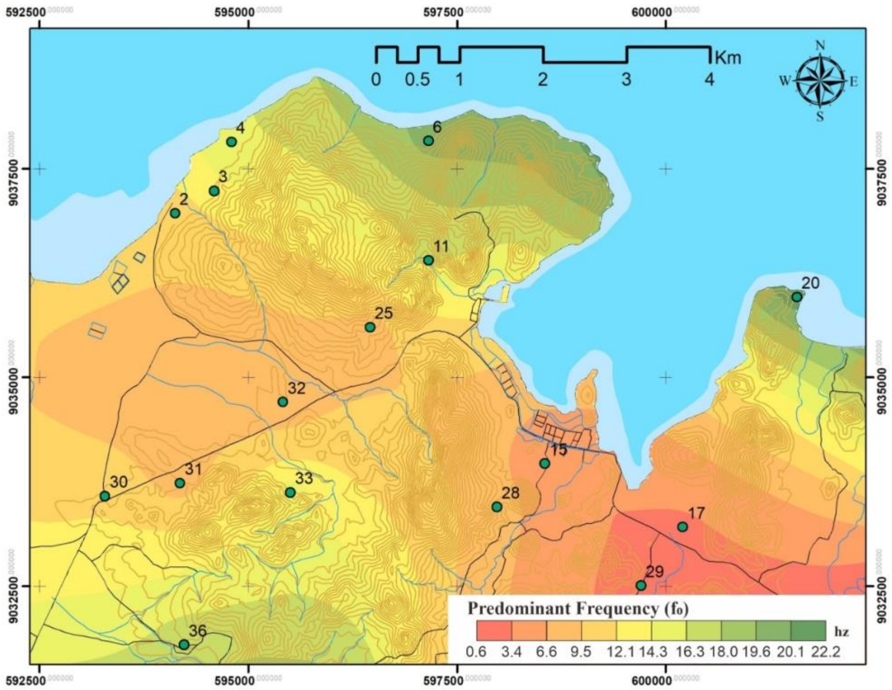

Figure 4. Predominant Frequency Distribution in Plampang. [12]

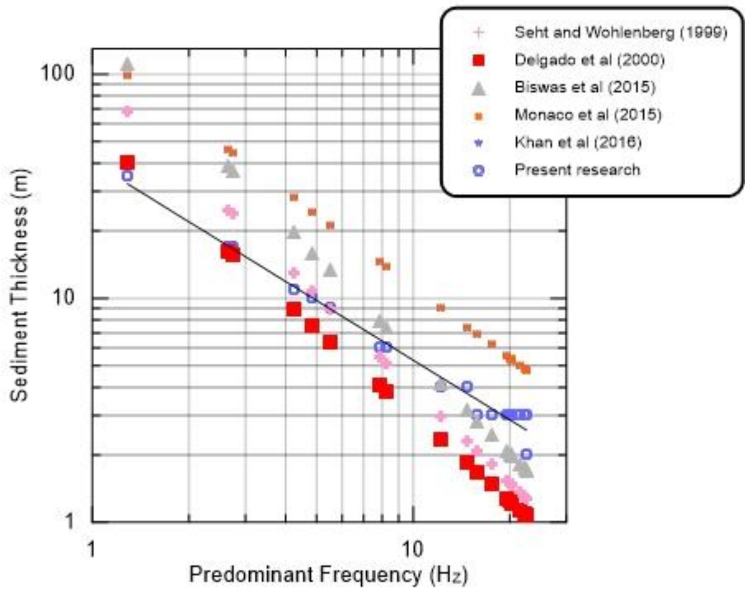

Figure 5. Empirical relationship between predominant frequency and sediment layer thickness in Plampang area.

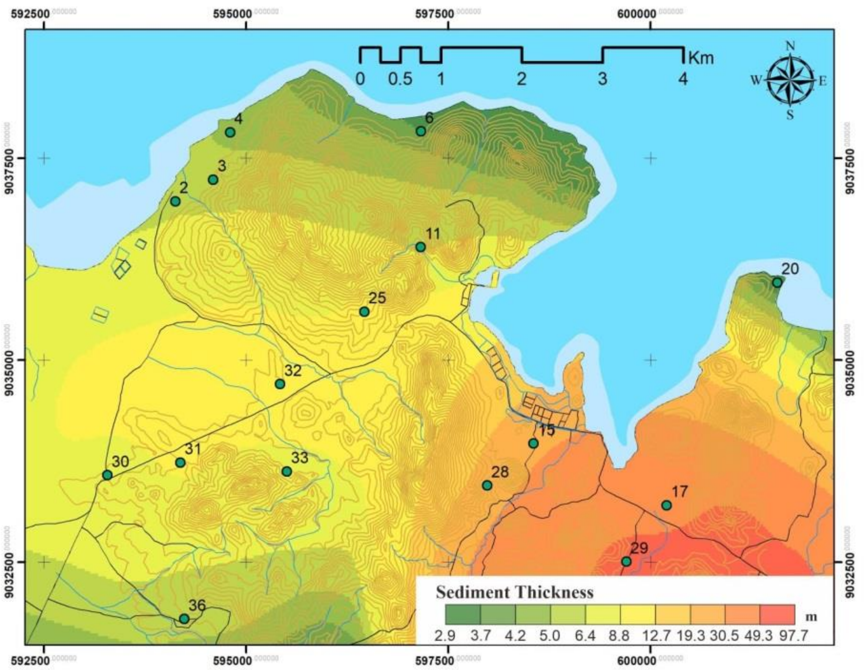

Figure 6. Distribution of sediment layer thickness around Plampang. [12]

CONCLUSION

This research was conducted with the aim of determining the empirical formula that will be used in mapping the thickness of the sediment layer above the bedrock in Plampang, West Nusa Tenggara. Single station microtremor measurements were carried out at 20 points, and then the predominant frequency magnitude was calculated based on the maximum spectral value of the H/V comparison method. Then, the thickness of the sediment layer was obtained from the shear wave velocity of the SPAC microtremor results. The results of the mapping of sediment thickness based on the empirical formula for the Plampang area show a good correlation with the predominant frequency and also show a good correlation with the results of the formula that has been carried out by previous studies. The important thing to note is that it still needs to be double-checked with geotechnical drilling data to get the accuracy of the thickness of the sediment layer.

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