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Spectrum and Time-Frequency Analysis to Characterize Microtremor Data in Sepaku Sub-District, East Kalimantan

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Abstract

Microtremor analysis has been done in the Sepaku Sub-District as a part of the New Capital City of Indonesia. This study aims to determine the characteristics of microtremors in the Sepaku Sub-District using Spectrum Analysis and Time-Frequency Analysis (TFA). Data in this study were taken using a seismometer on the 18 measurement points. The data were processed using default analysis from Geopsy software. Spectrum analysis and TFA used Fourier Transform to change time domain data into the frequency domain. Both analysis ways result in the characteristic microtremor data in the research area. The spectrum analysis data obtained shows two frequency ranges with maximum peaks: middle-frequency (5-8.8 Hz) and high-frequency (11.5-17.6 Hz). Afterward, the TFA shows similar results, where the characteristics of microtremor data are divided into two zones. The maximum peak occurs at the middle-frequency range of 5-10 Hz, and the high frequency ranges above 10 Hz.

Introduction

East Kalimantan was designated as the Ibu Kota Nusantara (IKN) or national capital of Indonesia because it was considered to have a low level of natural disaster risk compared to other places in Indonesia, such as Java and Sumatra. However, this case does not guarantee that the East Kalimantan region is accessible to the risk of natural disasters because three main faults are still active: the Maratus, Mangkalihat, and Patemoster [1]. Apart from that, the potential risk of a tsunami that could be caused by landslides on the seabed in the Makasar Strait also needs to be watched out for [2].

Sepaku Sub-District, Penajam Paser Utara Regency, is the area that is the central location for the construction of the National Capital City (IKN). Geomorphologically, the IKN area has a folded structure composed of clay and sand, which means that the top of the anticline tends to be fragile and prone to erosion [3]. Morphological structures in the form of anticlines and geology composed of sedimentary rocks such as sand and clay need to be watched out for because they can influence the propagation of seismic waves. Seismic waves can experience amplification when they propagate through rock layers in fine-grained sediment, which has inter-pore spaces where the waves can be amplified [4].

One effort can be made to reduce the risk of natural disasters caused by seismic activity with local topographic and geological conditions using the microtremor method. Microtremors can also be interpreted as harmonic vibrations of the ground that occur continuously, trapped in the surface sediment layer with a certain frequency content [5]. This method is used to measure, analyze, and utilize microtremor data to study the seismic properties of an area. Microtremor measurements were carried out to determine the dynamic characteristics of the soil [6]. Microtremor signals travel through rocks on the surface as elastic waves. The geological conditions in an area influence the response to microtremor signals, so the characteristics of microtremors reflect the geological features of a site [7].

This research was specifically conducted to study the characteristics of microtremor data in the Sepaku Sub-District, North Penajam Paser Regency. The attributes of microtremors can be seen from the frequency and amplitude content resulting from microtremor measurements. The frequency and amplitude content of the microtremor measurement data are determined using spectrum analysis and time-frequency analysis (TFA). Spectrum analysis is one of the analyses used to determine the predominant frequency content at each measurement point. TFA is an analysis used to determine the frequency distribution of the two components of the measurement results in the frequency and amplitude domains over time [8]. The results of spectrum analysis and TFA on the microtremor data at specific regions can be used in future infrastructure planning and disaster mitigation risk.

Theory and Calculation

Microtremor

Microtremors are natural vibrations that can originate from natural phenomena or human activities. Microtremors that arise from nature can be interpreted as natural harmonic vibrations of ground vibration that occur continuously caused by micro-vibrations below the ground surface or other natural activities. In contrast, microtremors originating from humans are ground vibrations due to various human activities, such as industrial activities and traffic [9]. Microtremors are also known as ambient noise. Ambient noise is a vibration originating from the ground with a certain amplitude that can describe the geological conditions in the area [6]. Natural waves from microtremors can show different characteristics depending on the conditions in the region [10].

Spectrum Analysis

Spectrum analysis is a form of seismic signal analysis that can be used to determine the frequency content of a signal using transformation functions, such as Fourier Transform. Spectrum analysis using the Fourier Transformation is an integral transformation that can change a signal as a function of time into a frequency. Seismic data, which is naturally not stationary and has a frequency content that varies with time, can be analyzed for each frequency content based on the Fourier Transform [11]. The Fourier transform function can be expressed in equation (1), and the inverse function can be written in equation (2).

$$f_\omega = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} f(t)e^{-i\omega t}dw \quad (1)$$

$$f_t = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} f(\omega)e^{-i\omega t}dw \quad (2)$$

The Fourier transformation results in a spectral density distribution that characterizes the amplitude and phase of the various frequencies that make up the signal [14]. The essence of the Fourier Transform is to divide or split the signal into sinusoidal waves where the number of signals that have been split is the same as the number of the original signal. Fast Fourier Transform (FFT) is used to speed up the calculation process in the Fourier Transform in digital computing [12].

Time-Frequency Analysis (TFA)

TFA is a form of signal analysis simultaneously in the time and frequency domains. The main goal of TFA analysis is to understand signals and their transformations. According to Cohen (1995), signal characteristics will be easier to understand if two things are combined as a two-dimensional object rather than studied separately [13]. This analysis obtains a TFA image as a spectrogram curve, which provides information on the amplitude distribution in the frequency and time domains [8].

Seismic signals consist of various waves coming from several reflectors; signals can be windowed in signal spectrum analysis into small periods. The local signal frequency for that period can be determined by converting this segment to the frequency domain or the Short-Time Fourier Transform (STFT) method. In signal processing, STFT divides the signal into shorter time segments and then applies the Fourier transform to each time segment. Thus, STFT observes signal energy changes over time and frequency [14].

Experimental Method

The research was carried out in the Sepaku sub-district, Penajam Paser Utara Regency, East Kalimantan, which is part of the National Capital City (IKN) planning area using a set of microtremor equipment in the form of a 3D Land Geophone Mod. Gemini 2. Data collection was carried out on 18 measurements spread over an area of approximately 28 km^2, representing the entire research area's conditions (Figure 1). Data was collected by placing the microtremor instrument at the measurement point and adjusting it towards the north. The tool's position must be balanced, referring to the water passing through the device. Data was collected at each point for approximately 30 minutes to reveal natural frequencies above 0.5 Hz [15]. The raw microtremor data consists of three components, namely the vertical component (Top and Bottom), the horizontal component (North-South), and the horizontal component (East-West) in the form of time domain data. The measurement output data were saved into SAF format and then processed using Sessaray Geopsy software to obtain the dominant frequency [16].

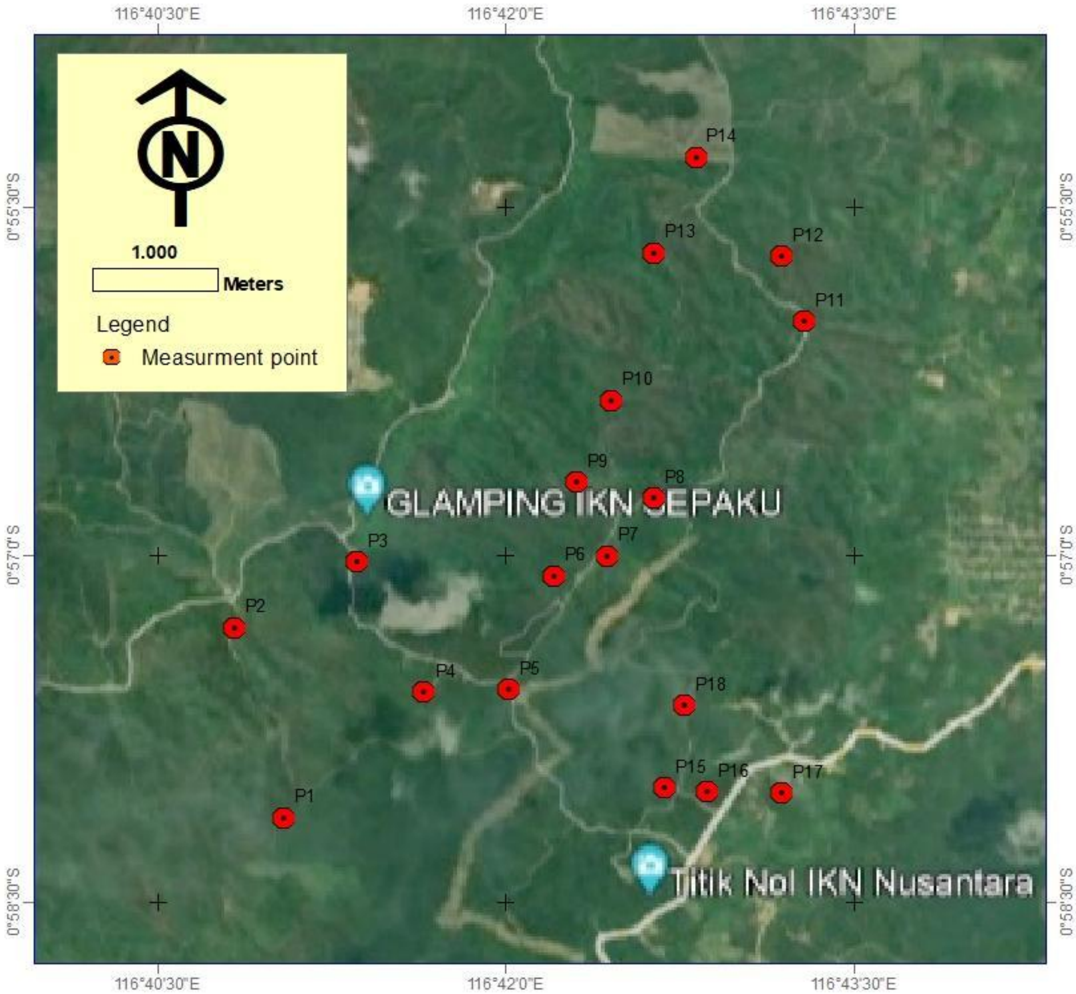


Figure 1. Map of the Research Area, Sepaku Sub-District, Penajam Paser Utara Regency. Red Marks represent the location of measurement points.

Result and Discussion

The characteristics of microtremors can be figured out from spectrum analysis and time-frequency analysis (TFA) [17].

Spectrum Analysis Results

The raw data was processed using Sessary-Geopsy software by applying a bandpass filter type with a frequency range of 5 Hz to 25 Hz to produce a stationary signal showing microtremor wave characteristics. Additionally, set the window duration to 20 seconds and manually select the window to remove data that contains a lot of transient noise, such as passing vehicles, people walking, or the wind. Based on the SESAME European Research Project (2004), the window length has a minimum requirement of Iw= 10/fo. In this case, lw is the window length, and fo is the resonant frequency; therefore, each window has at least ten significant cycles. By estimating the frequency value in the research area above 0.5Hz, the selected window width is 20 seconds [15]. An example of windowing processing visualization of microtremor data points in P3 can be seen in Figure 2.

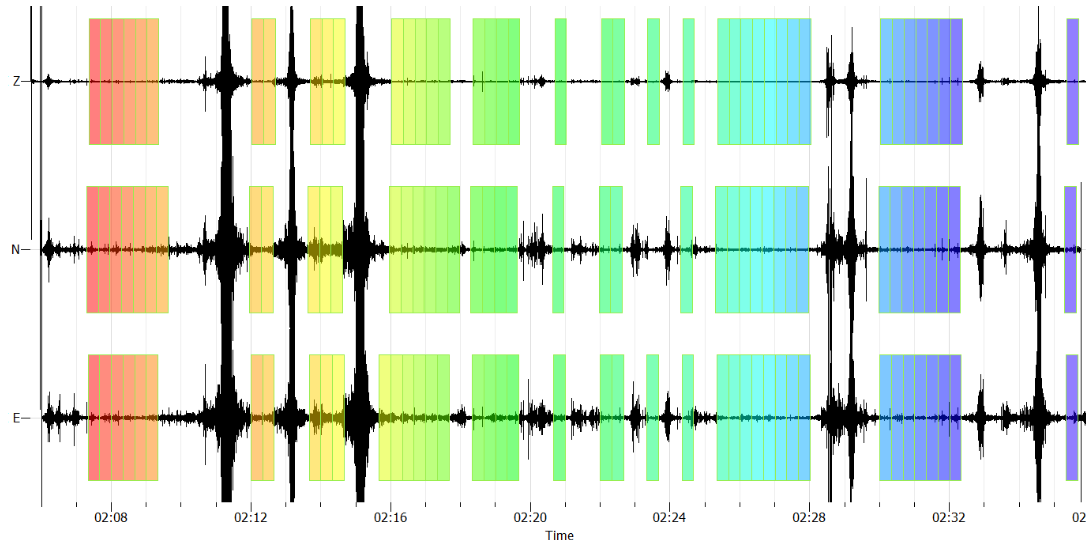
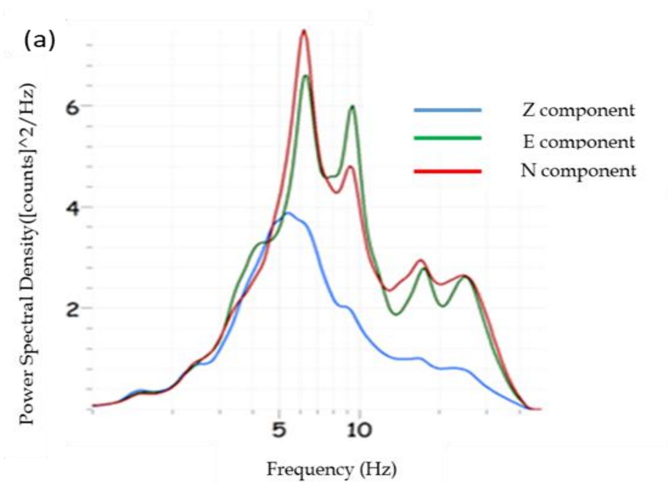


Figure 2. Shows the windowing process on raw data of measurement point P3 as time domain form. The raw data consists of three components, namely Z (vertical up-down), N (horizontal north-south), and E (horizontal east-west).

The following procedure is a Fast Fourier Transform (FFT) to convert the signal from the time domain to the frequency domain as a spectrum curve. The spectrum curve shows the power spectrum density vs frequency in Figure 3. These examples of a spectrum curve image resulted from spectrum analysis from two measurement data points, P11 and P3, respectively, consisting of three components: the vertical component (Z) and the horizontal component (N and E). Spectrum curve (a) represents the microtremor characteristic of measurement point P13, where the maximum spectrum peak stands at a frequency value of 6.2 Hz. However, spectrum curve (b) represents the characteristic of microtremor data from point P3, where the maximum spectrum peak reaches 17.6 Hz.



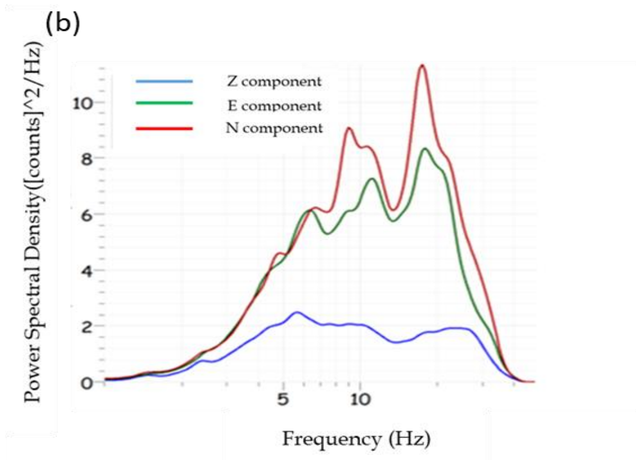


Figure 3. Shows spectrum curve of microtremor data, which consists of three components, namely vertical (Z), Horizontal East-West (E), and Horizontal North-South (N): (a) spectrum curve at P13; (b) spectrum curve at P3.

Microtremor data from 18 measurement points was processed, and frequency at spectrum peak was obtained. The results of spectrum peak analysis were grouped into two main categories: the maximum spectrum peak appeared in the medium-frequency category (5-8.8 Hz), and the maximum spectrum peak occurred in the high-frequency category (11.5-17.6 Hz). There are 12 measurement points with peak spectrum characteristics in the medium-frequency category and the remaining 6 points in the high-frequency category. The spectrum peaks of each issue are shown in Table 1.

Time-Frequency Analysis (TFA) Results

TFA analysis was carried out through several stages, including (1) microtremor data in the time domain was filtered using a bandpass filter to select a specific frequency range and to reject other frequency ranges outside the band; (2) The data were divided into several periods known as short-time Fourier transform (STFT), each time segment has a duration around 5-30 seconds. The output from STFT is a spectrogram curve from each measurement data point. The characteristics of microtremor data on the study area can be grouped into two zone categories based on the spectrogram image's similarity pattern, which shows the distribution of frequency and amplitude on the TFA curve. Figure 4 presents examples of a spectrogram visualization of TFA results from two microtremor measurement points, specifically P11 and P3, that compose three components, namely the vertical components (Z), horizontal east-west components (E), and horizontal north-south components (N).

Figure 4 (a) shows the characteristic spectrogram patterns of microtremor data at measurement point P13, which is included in the Zona-I category. The low-frequency range (below 5 Hz) and high frequencies (above 10 Hz) present low amplitude (0-20 µm), which is indicated by the intensity of the dominant red color mixed with a slightly yellow. However, the green color intensity combined with a slightly blue dominant in the medium frequency range (5-10Hz) indicates medium to high amplitude values (above 20 µm) in both horizontal E and N components. Different spectrogram patterns of microtremor data at measurement point P3 are shown in Figure 4 (b), which is included in the Zona-II category. At the vertical component (Z), the low-frequency range below 5Hz and the medium-frequency range (5-10Hz) has an amplitude that varies from low to medium (0-20 µm), which are characterized by the intensity of red and yellow, mixed with green color, while high amplitudes (above 20 µm) marked by green to blue color appear in the high-frequency range (above 10Hz). The horizontal components E and N both have similar spectrogram characteristics of microtremor data, where the low-frequency field below 5Hz and the medium frequency range 5-10 Hz stand to low and medium amplitude values (0-40 µm) marked by red, yellow, and mixed with slightly green. The green to blue color dominates in the high-frequency range (above 10Hz), indicating medium to high amplitude values (above 40 µm).

Table 1. Shows Frequency values for maximum spectrum peak in each measurement point.

Measurement Point	Easting (m)	Northing (m)	Spectrum Peak (Hz)
P1	464859	9892901	6
P2	464465	9894413	5.4
P3	465436	9894935	17.6
P4	465977	9893900	6.8
P5	466649	9893924	7.2
P6	467011	9894824	11.4
P7	467441	9894984	7.3
P8	467813	9895445	8.8
P9	467192	9895570	13.4
P10	467470	9896218	5
P11	469012	9896846	6.2
P12	468834	9897366	6.2
P13	467810	9897392	5.2
P14	468146	9898151	5.4
P15	467897	9893140	11.9
P16	468240	9893107	11.9
P17	468830	9893097	7

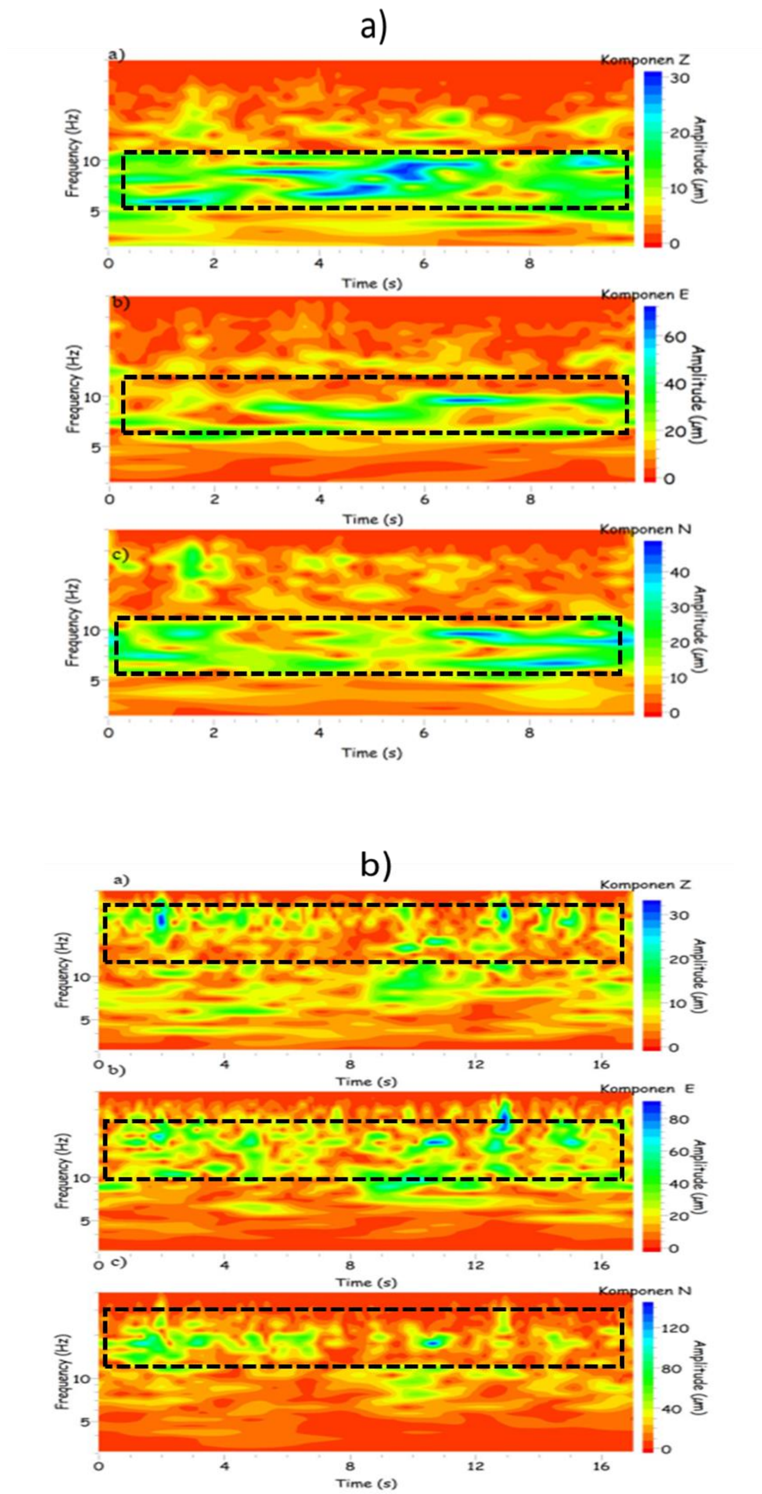


Figure 4. Displays the spectrogram curve of Time-Frequency Analysis (TFA) results at measurement points (a) P13, including Zone-I, and (b) P3, including Zone-II. Black Decide lines show the characteristic pattern of the spectrogram curve.

The results of the spectrogram pattern using TFA are similar to the spectrum analysis results, where the maximum spectrum peak occurs in two frequency range categories. The first category has peaks in the medium-frequency range of 5-8.8 Hz in the spectrum curve and 5-10 Hz in the spectrogram image. Meanwhile, the second category presents maximum peaks in the spectrum curve and spectrogram image in the high-frequency range, 11.5-17.6 Hz and above 10 Hz, respectively. The distribution of frequency values for each peak on the spectrum curve can be seen in Figure 5. In general, high-frequency values (yellow and red color) are spread out at the center of the research area, and at the edge of the distribution map, it presents medium frequency values (green color).

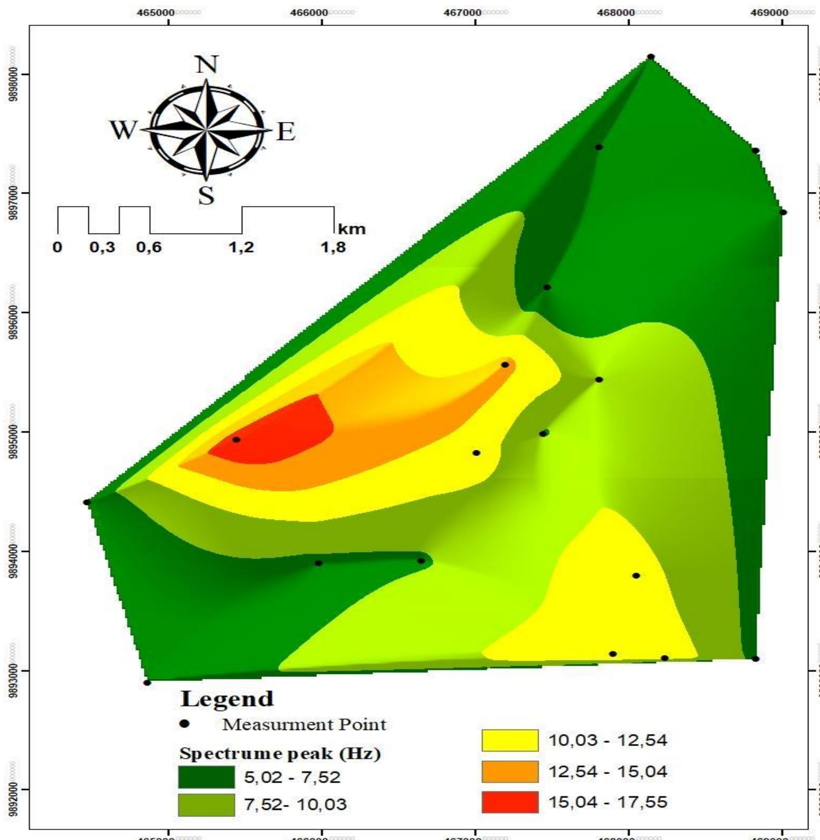


Figure 5. Shows the distribution of frequency values of spectrum peak on the research area.

Based on soil classification proposed by Kanai (1983) [18] in terms of the dominant frequency value (frequency value at a maximum spectrum peak), the spectrum peak appears at medium-frequency ranges classified as a rock type I. This type is characterized by alluvial rocks consisting of sandy gravel, hard sand, clay, or others, estimated by medium thick sediment surface ranging from 5-10 meters. Apart from that, the analysis results had been carried out on both spectrum and spectrogram curves showing the maximum peak appears in the high-frequency ranges, which are included as the rock type II, namely tertiary sedimentary rock or old rock that may be composed of hard sand and gravel with a fragile sediment surface. These results align with geological information in the research area where this location contains unit rocks from the Pamaluan Formation, such as claystone, shale, marl insertion, and sandstone, which are very old and hard, and the structure is relatively stable [19]. Although characteristics of microtremors show that the research area is relatively safe from earthquake threats, various other factors need to be considered, such as the interaction of local faults, folding, and fragile surface sediments that are easily eroded.

Conclusion

Based on the conducted research, it can be concluded that the characteristics of the microtremor data in the study area reveal two categories of frequency ranges; the first is spectrum peaks located on the medium-frequency range of 5-8.8 Hz from spectrum analysis and 5-10 Hz from spectrogram image of TFA analysis. The second category presents maximum peaks in the spectrum curve and spectrogram image in the high-frequency range of 11.5-17.6 Hz and above 10 Hz, respectively.

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