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Research Paper

Spatio-Temporal Changes on Spectra of Hydrothermal System at Arjuno-Welirang Volcano Complex, Indonesia

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ABSTRACT: *Arjuno-Welirang Volcano Complex, East Java of Indonesia, is one of the volcanic complexes whose volcanic activity is associated with geothermal systems. Microseismic surveys used in this study to record tremor signals that are usually used for seismicity studies caused by hydrothermal activity under the geothermal prospect area. Identification of spatio-temporal signals data in the area around hydrothermal manifestations at the Arjuno-Welirang Volcanic Complex shows how the frequency characteristics of tremors changed that later on indicate the characteristics of hot fluids changes too. The tremor signal was identified by performing a spectra from spectral analysis. Spectral analysis was carried out in 4 periods, from 2015, mid-and-late 2016 and 2018. The dominant frequency in period 1 has a value in the range of 13-24 Hz, while in period 2 has 15-16 Hz, period 3 has 12-20 Hz and period 4 has ~8 Hz. Moreover, tremor signal pattern in all periods shows the shape of the spectrum whose peak distribution is random and there is no periodic repetition (not harmonic) so the tremor at Arjuno-Welirang Volcano Complex are classified as spasmodic tremors.*
KEYWORDS: *Microseismic, tremor, spectrum, dominant frequency*

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I. INTRODUCTION

Indonesia is known as the country with the largest potential of geothermal energy in the world (~40%) due to its location in the ring of fire. Geothermal energy in Indonesia is spread over 331 points along the volcanic belt path from Sumatra Island, Java, Bali, Nusa Tenggara, North Sulawesi to Maluku. The study of geothermal energy in Indonesia became interesting to learn, since geothermal is a renewable energy that is formed from the continuous transfer of heat between rocks and hot fluids beneath the earth's surface. It's a interesting sustainable energy source due to its almost unlimited supply.

Arjuno-Welirang Volcano Complex, located in the east of Java Island, is one of the volcanic complexes in Indonesia whose volcanic activity is associated with geothermal systems. Geothermal sources are estimated to originate from the bottom of the Welirang mountain crater associated with andesite rocks [1]. Geothermal potential in this area is quite large, with an estimated energy of 280 Mwe [2], indicated as hydrothermal system [3] with high enthalpy temperature ($\sim 250^0$ C) [4].

The hydrothermal system includes hot fluids that come out and form manifestations that appear on the surface in the form of a hot spring. Hot springs in the Arjuno-Welirang complex are spread in Padusan, Coban and Cangar [5], while in this study focuses on cangar hot springs. The existence of geothermal manifestations occurs due to the propagation of heat from the subsurface and due to rock fractures [6] which allow geothermal fluid (steam and hot water) flowing to the surface [7]. Hot fluid has a high temperature which if it passes through rock fractures causes an increase in pressure below the surface, which continuously produces micro-earthquakes as a form of release of the energy of the hot fluid.

One method in geophysical field, namely seismic surveys, can record earthquake signals that are usually used for seismicity studies caused by hydrothermal activity under the geothermal prospect area [1]. Earthquake signals commonly used are signals from continuous earthquakes or also called tremor. The microseismic method was used in this study because of the compatibility between the vibrational magnitude to be recorded by seismographs with tremor vibrations in volcanic areas. Identification of tremor signals in the area around hydrothermal manifestations at the Arjuno-Welirang Volcanic Complex can show the characteristics of hot fluids. The tremor signal was identified by performing a spectra (spectral analysis) to determine the frequency of tremors as had been done in several volcanoes, such as Mount Semeru [8]–[10], Mount Raung [11], Mount Sakurajima [8], and etc. Spectral analysis shows a spectrum distribution, characterizing the amplitude and phase of the various frequencies that make up the signal [12]. This frequency spectrum can be used as physical information contained in the signal that has been analyzed. To analyze the hot fluid dynamics in the Arjuno-Welirang Volcano Complex, spatio-temporal signal data is needed. Spatio-temporal data is spatial data whose values change over a period of time [13]. The results of the spectral analysis on the data on tremor signals that are spatio-temporal later can show how the frequency characteristics of tremors change in the geothermal area of the Arjuno-Welirang Volcano Complex.

II. MATERIAL METHOD

Data. The data used in this study was microseismic recording data in the Arjuno-Welirang Volcanic Complex which was divided into 4 time periods, including in June 2015 (points CR1, CR2, CR3, CR4, CR5, CR6, CR7), May 2016 (points CF1, CF2), November 2016 (points CF3, CF4, CF5) and May 2018 (point CA). As can be seen in Figure 1 was the position of the measurement station and the contour map around it. Data from microseismic recordings in the form of digital recordings were carried out continuously at each measurement station. The recorded data in each station consist of three components, which were *Up-Down (UD), East-West (EW) and North-South (NS)* as shown as in Figure 2. The seismometer used to record data was Digital Portable Seismograph TDL-303s type with a sensitivity of 2V/g and frequency response 0～200Hz. Data recording was conducted by using a sampling interval of 100 Hz or 0.01 second. The recorded data would be stored in the default software from the seismometer (*DataPro*), then downloaded with *NetRec software* so that the data was stored in the trace data format (**.trc*).

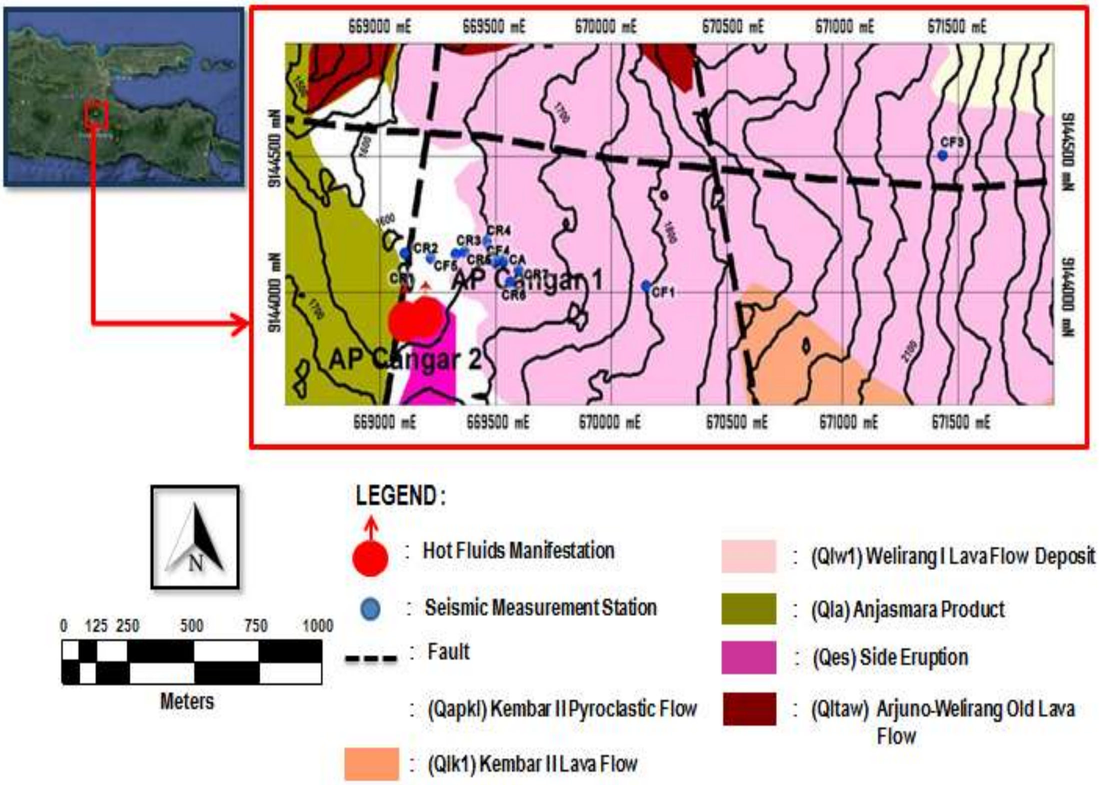

Figure 1. Location of Microseismic Measurement Station used in this study, contour map and geological map around Arjuno-Welirang Volcano Complex, Indonesia

Data Selection. The next step was data selection of tremor event, in this process the tremor event selection was performed manually using *Geopsy 2.10 Software*. By using this software, we cut tremor events according to the time of occurrence [14]. If data selection had been carried out, the data format was converted to miniSeed (**.MSD*) and ASCII (**.asc*), then filtered using the Band Pass Filter to remove frequencies outside the unexpected range. The expected frequency range was from 0.05 Hz to 30 Hz, while the frequency below 0.05 Hz was considered as noise.

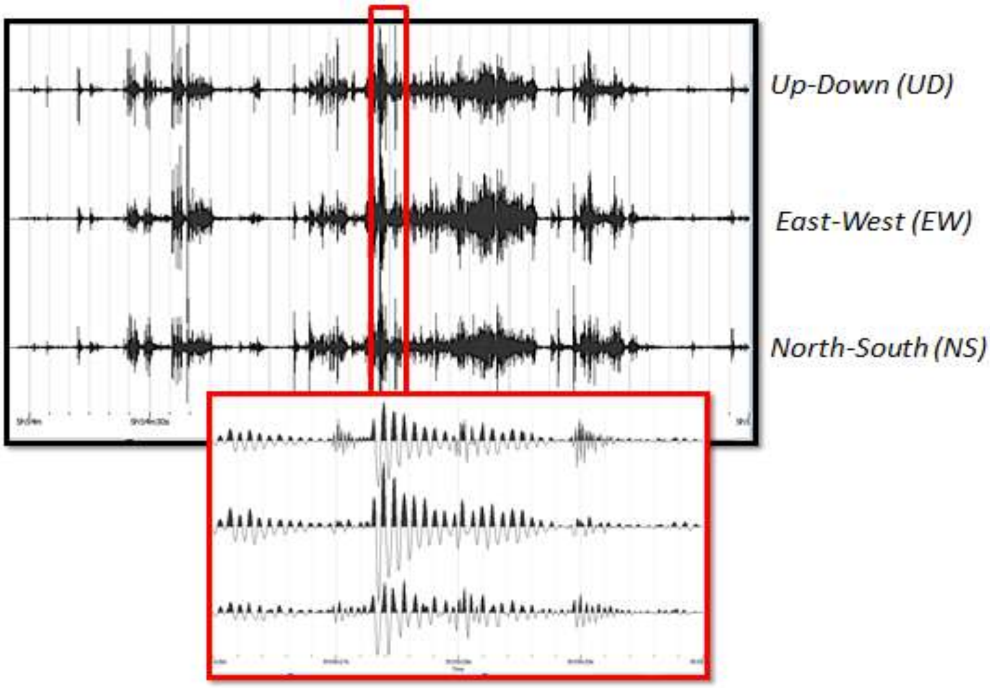

Figure 2. Microseismic recorded at Arjuno-Welirang Volcano Complex, Indonesia

Spectral Analysis. Spectral analysis is an analysis carried out to determine the frequency spectrum of a signal. The peak of the spectrum shows the dominant frequency of a tremor event. This process was basically a process for estimating unksnown parameters in a random function obtained from a measurement by statistics method. The aim was to filter useful information and dispose of unwanted information from observational data. Seismic recording data (seismogram) was time domain data, because the recording data uses P and S wave arrival times which were influenced by wave propagation effects. To simplify the analysis process, the data in the form of time domains were converted into frequency domains using Fourier transforms theorem. Fourier transform theorem can be written by equation (1).

$$X(f) = \int_{-\infty}^{\infty} x(t)e^{-j2\pi ft}dt \rightarrow (1)$$

Where *X(f)* is signal function in frequency domain, *x(t)* is signal function in time domain, $e^{-j2\pi ft}$ is Kernel function, *f* is frequency in Hz and *t* is time in sekon.

There are two ways to do spectral analysis, namely directly and indirectly estimation. Direct estimation is applied by transforming directly on raw data to obtain the spectral by applying FFT (Fast Fourier Transfrom). While the indirect estimation can be done by an average periodogram method. In this study, spectral analysis was estimated directly with the help of *OriginPro 2016 Software*. In addition to determining the dominant frequency of tremor signals, through the frequency spectrum we can see the visual appearance of the tremor signal pattern. Then that tremor signal pattern can be identified based on the characteristics of the volcanic tremor of Minakami (1974).

III. RESULT AND DISCUSSION

Tremor events had been selected from raw data (microseismic recordings at each station), based on their continuous wave appearance. The length of data for each event varies depending on the duration of the occurrence, seen through the amplitude that changes suddenly and significantly. The tremor event was then filtered at a predetermined boundary and produces new data that contains the waveform from the tremor event (Figure 3a). FFT theorem was used in waveform data to obtain spectra from tremor. As seen in Figure 3b, data that initially has a time domain becomes a frequency domain. The peak of the spectrum with the greatest amplitude was the dominant frequency of the tremor event. This dominant frequency is a value parameter, indicating the physical characteristics of the tremor signal, and later can be used as supporting data for further analysis. In addition to knowing the dominant frequency of tremor, the waveform data provide information that tremors in the area around Arjuno-Welirang complex were classified as spasmodic tremors. This is based on the type of volcanic tremor by T. minakami 1974, where spasmodic tremors have a spectrum shape in which the peak distribution was random and there was no periodic repetition (not harmonic).

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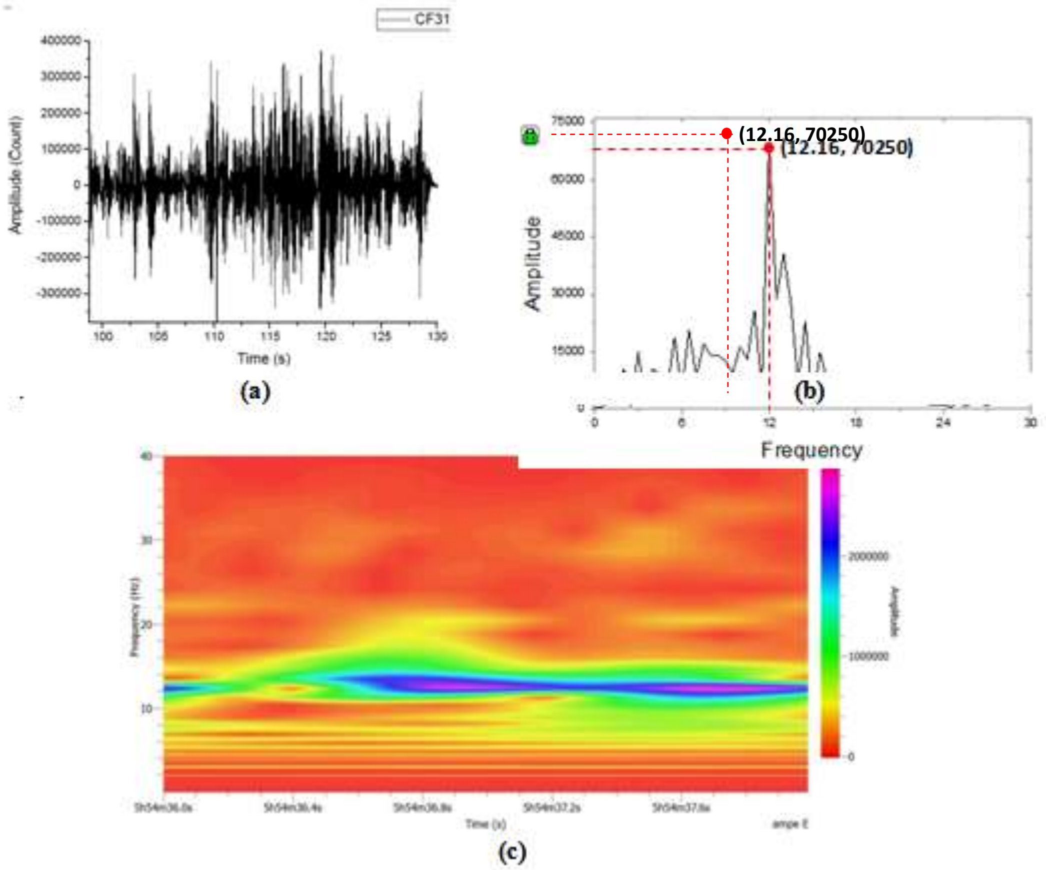

Figure 3. Tremor event around Arjuno-Welirang Volcano Complex ; (a) Waveform, (b) Spectrum distibution, (c) Spectogram

As well as spectra but with other displays, the spectogram (Figure 3c) also shows information on tremor signals. When on the spectrum, the time domain was converted into a frequency domain, different from the spectrogram where both the frequency and time are displayed. In the spectogram, the x axis shows time, the y axis shows the frequency (Hz), and the color scale shows the amplitude (count). In Figure 3c, the largest amplitude was expressed in purple, this means that in the tremor event with an interval of 5h54m36s to 5h54m37,8s it has a dominant frequency 12 Hz.

Spatio-temporal changes of spectra were described as changes in the value of the dominant frequency from microseismic data in different station location but are still close together, with a certain period of time, which in this study was divided into 4 time periods. We divide the time period based on the time of data collection in different months and years. Figure 4 shows the spectrum of one of the tremor events representing the four time periods in several microseismic measurement stations around Arjuno-Welirang Volcano Complex. The spectrum at CR1 station in June 2015 has a dominant frequency of 13.22 Hz (Figure 4a). While the spectrum at CF11 station in May 2016 has a dominant frequency of 14.94 Hz (Figure 4b). At CF32 station in November 2016, shows the spectrum with the dominant frequency 13,93 Hz (Figure 4c) and spectrum at CA06 station in May 2018 has dominant frequency 8,26 Hz (Figure 4d).

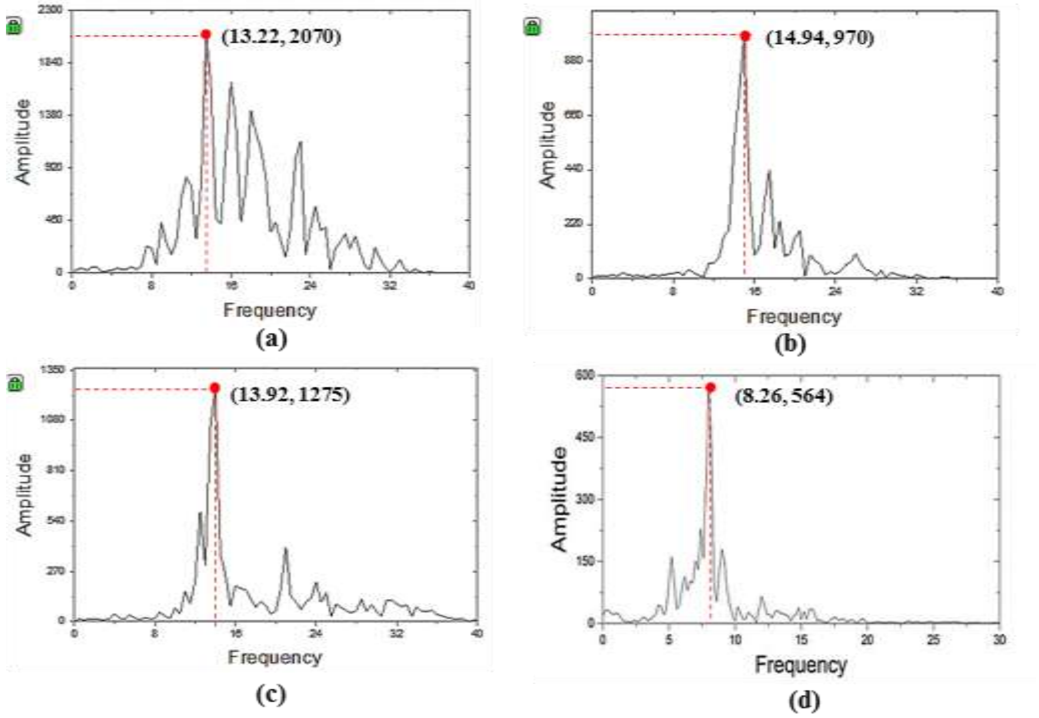

Figure 4. Spectra of tremor in several microseismic measurement stations around Arjuno-Welirang Volcano Complex; (a) Station CR1 in June 2015, (b) Station CF11 in May 2016, (c) Station CF32 in November 2016, and (d) Station CA06 in May 2018

The overall spatial-temporal changes in the tremor spectrum were presented in graphical form (Figure 5). The dominant frequency in period 1 has a value in the range of 13-24 Hz, while in period 2 has 15-16 Hz, period 3 has 12-20 Hz and period 4 has ~8 Hz. Dominant frequency values in periods 2 and 4 have lower values compared to periods 1 and 3, this was due to low rainfall around Arjuno-Welirang Volcano Complex in May 2016 (period 2) and May 2018 (period 4). Higher rainfall in June 2015 (period 1) and November 2016 (period 3) was expected to cause noise at the subsurface, causing a mixture of signals due to the movement of hot fluid with rainfall water. This allows the frequency spectrum in periods 1 and 3 to have a higher dominant value range.

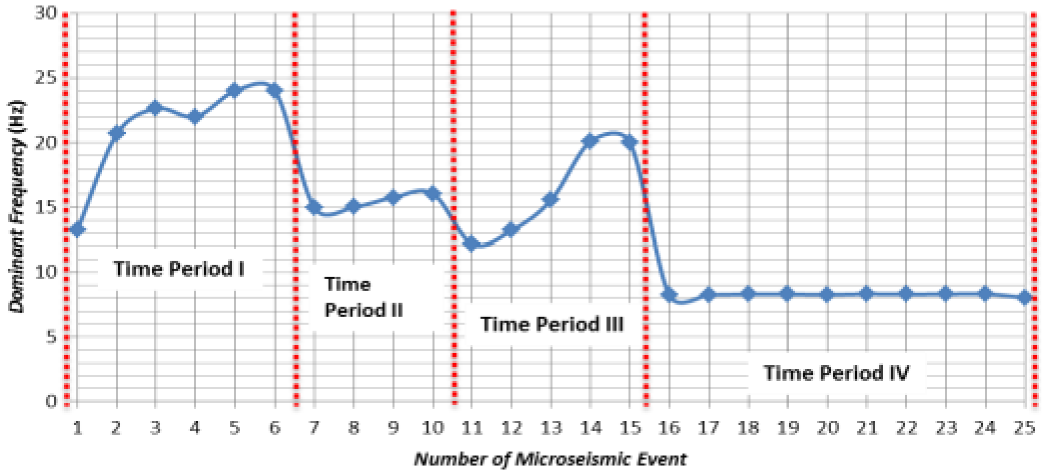

Figure 5. Spatial-Temporal changes of tremor events around Arjuno-Welirang Volcano Complex

While the dominant frequency value in period 4 was much lower and different from the previous three periods, estimated due to differences in hours of microseismic data collection. The microseismic data used was data taken at noon in the previous three periods, while data taken in period 4 was data at midnight. At noon, the emergence of urban noise was estimated to be higher. According to Gross and Ritter (2009), urban noise that can be included in microseismic data ranges is 1-45 Hz [15]. This was the reason why the dominant frequency in period 4 is lower, because the possibility of entering urban noise into the data was smaller than the previous 3 periods.

IV. CONCLUSION

Study of microseismic surveys at Arjuno-Welirang Volcano Complex was investigated to record tremor signals that are usually used for seismicity studies caused by hydrothermal activity under the geothermal prospect area. Identification of spatio-temporal signals data in the area around hydrothermal manifestations at the Arjuno-Welirang Volcanic Complex shows how the frequency characteristics of tremors changed that later on indicate the characteristics of hot fluids changes too. Spectral analysis was used in this study by grouping data into 4 periods, which are divided based on differences in the location of the measurement station points but are still close to each other, with a certain period of time. The dominant frequency in period 1 has a value in the range of 13-24 Hz, while in period 2 has 15-16 Hz, period 3 has 12-20 Hz and period 4 has ~8 Hz. The difference of dominant frequency in this study was estimated because of the influence of urban noise due to differences in the time of data collection. Moreover, tremor signal pattern in all periods shows the shape of the spectrum whose peak distribution was random and there was no periodic repetition (not harmonic) so the tremor at Arjuno-Welirang Volcano Complex were classified as spasmodic tremor.

V. ACKNOWLEDGMENT

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