Microseismicity of Blawan hydrothermal complex, Bondowoso, East Java, Indonesia

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Abstract. Peak Ground Acceleration (PGA), hypocentre, and epicentre of Blawan hydrothermal complex have been analysed in order to investigate its seismicity. PGA has been determined based on Fukushima-Tanaka method and the source location of microseismic estimated using particle motion method. PGA ranged between 0.095-0.323 g and tends to be higher in the formation that containing not compacted rocks. The seismic vulnerability index region indicated that the zone with high PGA also has a high seismic vulnerability index. This was because the rocks making up these zones were inclined soft and low-density rocks. For seismic sources around the area, epicentre and hypocentre, have estimated base on seismic particle motion method of single station. The stations used in this study were mobile stations identified as BL01, BL02, BL03, BL05, BL06, BL07 and BL08. The results of the analysis particle motion obtained 44 points epicentre and the depth of the sources about 15 – 110 meters below ground surface.

1. Introduction

Geothermal is one of the biggest potentials of the renewable energy sector in Indonesia. It was a natural source of energy derived from the rock interaction and heat flow beneath the earth’s surface. In Indonesia, there were 256 geothermal areas and have 27,441 MV of potential energy distributed from Nangroe Aceh Darussalam to Irian Jaya [1]. The geothermal system in Indonesia dominated by volcanic geothermal system (volcano hosted geothermal) that associated with a volcano quarter. It was commonly located in the Quaternary volcanic arc that stretching in Indonesia as well as for Blawan-Ijen Complex in East Java [2-6].

Some non-seismic geophysical methods have been applied to observe the existing of geothermal Blawan area. Based on the geo-magnetic result indicated the geothermal source volume estimated about 133.16 million m³ which has temperature around 70.2°C [5]. Geo-electric survey at Blawan identified the underground seepage of hot water which following the fault direction and river flow with some hot spring that founded which has temperature about 50°C [3]. Furthermore, the natural waters have been also identified with geo-electric survey and results it is in about 9-25 meters depth [7]. However, a seismic method had not been applied at Blawan volcano hosted geothermal area.
Basically, the geothermal system with hydrothermal type was formed as a result of heat transfer from source to its surroundings by conduction and convection [8]. The three-component seismic method is very effective used for exploration in the geothermal area. The seismic wave events as measurement results and the time function consist of three components i.e. two horizontal components (North-South and East-West), and one vertical component (Up-Down) [9].

The geothermal systems generally located in tectonic areas or high volcanic activity [10]. Almost all geothermal areas affected by regional geological structures. Microtremor as the passive seismic method record all motions generated by earth or human activities. Moreover, using the particle motion analysis in horizontal and vertical components could determine the distribution of the location of earthquake sources position (epicentre and hypocentre).

2. Methods

Seismic data recorded in Blawan-Ijen Complex, East Java at 10 mobile stations (BL01 – BL10). The station selected according to their event characteristics i.e. BL01, BL02, BL03, BL05, BL06, BL07, and BL08. The data recorded by TDS 3 components seismometer i.e. North-South (NS), East-West (EW) and Up-Down (UD). These three components will be used for seismic particle motion analysis. Time domain data was transformed into frequency domain using FFT (Fast Fourier Transform) to obtain the frequency spectrum of each component. In addition, spectrogram analysis was needed to know the variation of the signal frequency distribution. Then cut-off frequency determined for the filtering process and using band-pass Butterworth filter.

![Figure 1. Flowchart of methods used in this research.](image-url)
Particle motion of horizontal and vertical components plotted to estimate the epicentre and hypocentre of seismic sources. The amplitudes of EW and NS components plotted to obtain horizontal P-wave particle motions. The epicentres estimated by calculating the azimuth direction of horizontal particle motions. The amplitude resultant of both horizontal components plotted with the vertical components for predicting the hypocentres. Additional data such geological structure data at Blawan-Ijen Complex used for assuming the source positions influenced by the hydrothermal activities. The flowchart of the methods can be seen in figure 1.

3. Results and Discussion

3.1. Peak Ground Acceleration (PGA)

The acceleration of maximum ground vibration due to earthquake events was estimated by the attenuation function that formulated by scientist. Until now in Indonesia did not have its own attenuation function because the historical data of the earthquake was not enough to formulate the attenuation function. The Fukushima–Tanaka attenuation [11] was used in this research because the acceleration of land in the hills and mountains was assumed to have almost the same morphological conditions. In addition, this attenuation function had chosen because there were several fractures and fault indications in the research area so it was possible to use the function. Furthermore, the attenuation function by Young et al (1997) [12] also used because this function was considered appropriate for the research area as it was suitable for earthquakes with more than 200 km depths and was also suitable for subduction earthquake sources type.

From the calculation of the two functions, they were obtained different PGA results but has a similar plot contours. The value obtained from the calculation of Fukushima–Tanaka was smaller than the Young method. The result of PGA with Fukushima–Tanaka method ranged from 0.0953–0.3227 g while the method of Young attenuation obtained results between 1.7664–1.9464 g. Figures 2 and 3 were results of PGA calculation with attenuation function of Fukushima–Tanaka and Young.

Figure 2. Contour of Peak Ground Acceleration of Blawan area using Fukushima-Tanaka attenuation function.
Figure 3. Contour of Peak Ground Acceleration of Blawan area using Young attenuation function.

Based on figures 2 and 3, the values of the Peak Ground Acceleration were indicated by colour bar with the highest value shown in red colour. The areas with PGA values tend to be high at coordinates -8.15° LS 114.1° BT and -8.1° LS 114.28° BT. At coordinates -8.15° LS 114.1° BT has a PGA value of 0.3227 g for Fukushima–Tanaka and 1.946 g for Young attenuation. This large PGA by using Young attenuation tends to be high when compared to the Peak Ground Acceleration of Indonesian bedrock map [13] which only ranges from 0.15–0.25 g, but for Fukushima–Tanaka show the results which not different significantly. The variation of soil acceleration values influenced by the distance of hypocentre ($H$) and the magnitude of the earthquake which occurred around the area. The closer distance of the earthquake hypocentre to the point of observation showed a greater value of PGA. Similarly, the magnitude of the earthquake also provides a large PGA as well.

Regarding to geology of the region, there are faults that affects the earthquakes. In Blawan region, there are about 4 faults and graben which affect the acceleration value of ground vibration. The highest PGA values found in southwest of research area. This area was formed by predominantly eruption of Mount Raung which composed of andesitic lava, lava, pyroclastic flows, and pyroclastic fall. The physical properties of rocks which not too hard and compact indicated a high seismic vulnerability, like andesitic & breccias. Tuff sandstone (pyroclastic fall) which contain lapilli tuff and pumice stone also have less physical characteristics so it has an appreciable seismicity. The lava, which consists of breccias, tuff sand, lava block, andesitic and basalt, has a higher susceptibility, as well as alluvium deposits.

3.2. Particle Motion
Based on seismic particle motion analysis in Blawan Complex, Ijen Mountain, East Java, there are 44 spots of epicentre suspected as hydrothermal activity below earth surface. They are supported by the distribution of geothermal manifestations around the area. The dominant rocks and layers in Blawan Complex area, according to geoelectric and geomagnetic methods, are sedimentary layer which was deposit of Blawan Lake in the form of clay tuff, limestone sediments, gravel, water contained water, and layers of volcanic rocks which are breccias tuff of volcanic rock and basaltic lava. Lava rocks contain many cracks which become spaces for fluid flow (water). Cracks may occur due to volcanic as well as tectonic activities around Mount Ijen. Hot rocks will heat the fluids beneath the earth’s surface, it increased the hot fluid activity and cause earthquakes. Figure 4 explained the seismic epicentre points suspected to be an undiscovered hot spring.
Figure 4. Map of geothermal epicentre distribution at Blawan Complex Mount Ijen, East Java.

Figure 4 shows that the epicentre spread near the hotspots around study area. From the calculation using vertical component of particle motion shows 31 points of hypocentre below the study area. Some of them can be seen in table 1. From table 1, the hypocentres of events in study area are around 15 – 110 meters below the surface. Figures 5 show the distribution of hypocentre in study area. Figure 5a was hypocentre distribution in South-North section, while figure 5b was West-East section. From figures 5a and b shows that hypocentre distribution each events flow through every hot spots on earth surface.

Table 1. Some coordinates of hypocentre location around study area.

| No | Longitude (UTM) | Latitude (UTM) | Depth (m) |
|----|----------------|----------------|-----------|
| 1  | 188295         | 9115927        | 65        |
| 2  | 188252         | 9115973        | 80        |
| 3  | 188301         | 9115961        | 60        |
| 4  | 188372         | 9115916        | 20        |
| 5  | 188269         | 9115873        | 30        |
| 6  | 187876         | 9115882        | 40        |
| 7  | 188536         | 9116108        | 110       |
| 8  | 188480         | 9116276        | 15        |
| 9  | 188010         | 9116041        | 70        |
Figure 5. Hypocentre distribution of seismic events, (a) South-North section, (b) West-East section.

3.3. Seismic Vulnerability Index
Seismic vulnerability index was a value that can describe the level of surface layer susceptibility to deformation that occurs during earthquake. The seismic index obtained from the calculation of H/V parameters in the form of $A$ and $f_0$. Besides, to calculate seismic vulnerability of research area, H/V parameter can also used to know the dominant period of recorded microtremor. The dominant period can illustrate the geological condition of the research area so it can complete the information as the basis for the analysis of vulnerability and PGA values obtained. The results obtained from the HVSR method are in table 2.

| No | Point Name | $A$   | $f_0$   | Dominant Period (s) | Seismic Vulnerability Index |
|----|------------|-------|---------|---------------------|-----------------------------|
| 1  | BL01       | 0.526 | 2.49    | 0.401606            | 0.111115                    |
| 2  | BL02       | 0.849 | 4.65    | 0.215054            | 0.155011                    |
| 3  | BL03       | 10.749| 4.16    | 0.240385            | 27.77428                    |
| 4  | BL04       | 1.806 | 7.68    | 0.130208            | 0.424692                    |
| 5  | BL05       | 6.134 | 1.522   | 0.65703             | 24.72139                    |
| 6  | BL06       | 0.747 | 4.01    | 0.249377            | 0.139154                    |
| 7  | BL07       | 0.554 | 2.67    | 0.374532            | 0.11495                     |
| 8  | BL08       | 0.722 | 2.52    | 0.396825            | 0.206859                    |
| 9  | BL09       | 2.812 | 0.836   | 1.196172            | 9.458545                    |
| 10 | BL10       | 0.982 | 1.79    | 0.558659            | 0.538728                    |
The value of dominant period can be used to determine the geological condition of the study area. Based on the results, the dominant period at point BL01 was 0.401606. According to the soil classification of Kanai & Tanaka [14] and Omote-Nakajima [15] conversion in Table 3, the dominant period value of BL01 was 0.40, which is III/B type. This type of soil indicates the presence of alluvial rocks consisting of gravel, hard clay sand, and clay, but they were still unknown formations. Points BL02, BL03 and BL04 obtain different dominant period values but all three include in the same type of soil, i.e. II/A type. The soil conditions of II/A type were almost identical to the III/B type soil comprising gravel, hard clay sand, and clay with a thickness of 5 meters. At point BL05, the dominant period value that tend to be high, amount to 0.65703. The high dominant period value indicate the classification of IV/C type soils composed of alluvial rocks formed from delta, top soil, and mud sediment with a depth of 30 meters. The BL06 point indicates the II/A type with the dominant period value 0.249377. The points BL07 and BL08 have the dominant period values 0.374932 and 0.396825, both of them were classified in soil III/B type with soil conditions similar to II/A type, but they were still unknown formation. The points BL09 and BL10 included on the soil IV/C type because it has the value of the dominant period 1.196172 and 0.558659. Therefore, it was indicated alluvial rocks due to sedimentation delta, top soil and mud at a depth of 30 meters.

Table 3. Soil classification by Kanai–Tanaka and Omote–Nakajima modified from Parwatiningtyas et al (2013) [16].

| Soil Classification | Kanai-Tanaka | Omote-Nakajima | Dominant Period (s) | Specification                                      |
|--------------------|--------------|----------------|--------------------|---------------------------------------------------|
| I                  | A            |                | 0.05–0.15          | Tertiary rocks or older. Consists of hard sandy gravel |
| II                 | A            |                | 0.10–0.25          | Alluvial rocks with 5 meters width. Consists of sandy gravel, sandy hard clay, clay, and loam |
| III                | B            |                | 0.25               | Alluvial rocks similar with II type rocks           |
| IV                 | C            |                | >0.40              | Alluvial rocks formed from delta sedimentation, top soil, mud, etc with 30 meters depth |

The result of Seismic Vulnerability Index in table 2 also shows the higher values. When Seismic Vulnerability Index was larger, the risk of damage due to earthquake becomes greater. The high values of Seismic Vulnerability Index were affected by geological condition around the area. They related to wave amplification which propagated in soil layers or rocks. If the soil thickness relatively large associated with large amplification, the Seismic Vulnerability Index was relatively large too. Figure 6 presents the contour of Blawan Seismic Vulnerability Index. High Seismic Vulnerability Index was shown on red colour. Based on geological map (picture 2 and 3), the area with high Seismic Vulnerability Index such as BL03 and BL05 which shown on red colour in contour map were in sedimentary deposits of Blawan lake. It was characterized by the shrinkage between the shale and sand with a minimum thickness about 10 meters and consists of fossil, lime sediment, and hard. The rocks consist of andesitic fragment, basalt, pumice stone, quartz, and granodiorite. These rocks have less coherent structure so it has a high vulnerability. The materials of these rocks also affect the wave amplification, while the rocks which have low density (less coherent structure) will also have relatively high risk of damage.
4. Conclusion
Based on the results, the hypocentre located about 15 to 110 meters below the subsurface. While epicentre distributed around the hot springs of Blawan area. The existing of epicentre and hypocentre can relate to the existence of hydrothermal activity beneath the earth's surface. In addition, the maximum land acceleration value of the geothermal potential area of Blawan-Ijen East Java ranges from 0.093 to 0.322 for the Fukushima-Tanaka attenuation function and by 1.766 to 1.946 for Young attenuation function. Region with the largest PGA values located at coordinates -8.15° LS 114.1° BT and -8.1° LS 114.28° BT. The region was a zone that also has a high seismic susceptibility index due to soft-tending constituents and low rock densities.

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References
[1] Maryanto S 2017 Proc. 8th. Int. Conf. on Global Resource Conservation 198
[2] Maryanto S, Dewi C N, Syahra V, Rachmansyah A, Nadhir A and Santoso D R 2017 J. Geosci. 7 12
[3] Maryanto S, Suciningtyas I K L N, Dewi C N and Rachmansyah A 2016 Int. J. of Geophys. 2016 14
[4] Suciningtyas I K L N, Maryanto S and Rachmansyah A 2013 J. Natural-B 2 164
[5] Afandi A, Maryanto S and Rachmansyah A 2013 J. Neutrino 6 1
[6] Nuha D Y U, Maryanto S and Santoso D R 2017 J. Penelit. Fis. Apl. 7 2
[7] Wiyono, Soemarno, Maryanto S and Rachmansyah A 2017 *American J. Env. Eng.* **7** 10
[8] Gupta H and Roy S 2007 *Geothermal Energy: An Alternative Resource for the 21th Century* (Amsterdam: Elsevier) p 31
[9] Ihsan A B 2011 *Characterization of Microtremor at Porong River, Kebon Agung Sidoarjo* (Malang: Brawijaya University)
[10] Iguchi M *et al* 2012 *J. Disaster Res.* **7** 26
[11] Fukushima Y and Tanaka T 1990 *Bull. Seism. Soc. Am.* **80** 757
[12] Young R R, Chiou S J, Silva W J and Humphrey J R 1997 *Seism. Res. Lett.* **68** 58
[13] Irsyam M *et al* 2010 *Study Result Summary of Indonesia Earthquake Revision Team 2010* (Bandung: Bandung Technology Institute) p 29
[14] Kanai K and Tanaka T 1961 On Microtremors VIII *Bull. Earthq. Res. Inst.* **39** 99
[15] Omote S and Nakajima N 1966 *Proc. of Japan Earthq. Eng. Symp.* **1** 21
[16] Parwatiningsytas D, Ambarsari E W, Marlina D and Wiratomo Y 2013 *Proc. The 3rd. Int. Symp. for Sustainbale Humanosphere (ISSH)* **3** 46