Earthquake Risk Reduction Study with Mapping an Active Fault at the Southern of East Java

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Abstract. The southern part of Java Island is located between the two plates of the subduction zone, therefore this region had an active tectonic and volcanic activities. Those made a deformation of the geology around the southern part of Java island. This research was conducted to know the volume of deep geological structures to provide an overview of disaster warning systems in southern East Java region. The research that has been carried out using numerous active geophysical methods such as seismic methods had not been able to indicate internal structures. The needed for innovation used the integration of gravity and magnetotellurics methods. Bouguer anomaly gravity map became the supported data for interpretation. It showed low-density zones (0-80 mGal) between Pacitan-Trenggalek and beneath the Lumajang area which indicates the fault structure. Magnetotellurics (MT) which had a high penetration so that it is able to map deep active geological structures below the surface. The research area covered 8 regencies at the southern of East Java namely Pacitan, Trenggalek, Tulungagung, Blitar, Malang, Lumajang, Jember, and Banyuwangi. Magnetotelluric 1D processing showed indications of faults with orientations tend to be NE-SW between Pacitan and Trenggalek with depth (500 m – 8000 meter). Indications of faults with orientation tend to be NorthEast-SouthWest in Lumajang (100 - 500 meter).

1. Introduction
South East Asia Region was bounded by a Eurasian Plate from north to west and Indian-Australian Plate at the southern (Figure 1.) during the Cenozoic geologic time with some active microplates like Sunda and Banda Plate made up the unique tectonic [1]. Therefore, Indonesian ideal to earthquake and volcanism activity [2][3].
However, many basins in Indonesia are typically back arc basin that is located 100 km from the active volcanic arcs included offshore Northwest and East Java Basin [4]. Sunda-Banda subduction margin built the Quaternary Volcanic Arcs [5]. Current activities of earthquake occurred on the southern part of East Java which caused by tectonic activities like Grindulu Fault (NE-SW trend) in Pacitan, Klangon Fault in Madiun was triggered in 2015 and based on Meteorological, Climatological, and Geophysical Agency record data showed the rapid earthquake with less magnitude that occurred near Malang and Lumajang since a few last year until now. Figure 2 illustrated the active deformation in Java which accommodated by small-scale structures (km to tens of kilometers) with a wide spread and no dominant structures such as the sumatra fault [6]. Unfortunately, The revision of Indonesia Earthquake source map (2017) did not inform the land fault system which parallel with Opak Fault in Jogjakarta which had a trend tend to NE-SW.

![Figure 1. Indonesian Margin and Major Basins](image1)

This research have the objectives to map the active structural geology which develop at the southern east java particularly the fault at the surface (shallow) and basement (subduction zone) also its associated with the quaternary volcanic arcs. 1D Magnetotelluric-Electromagnetic methods is implemented because of non-destructive methods, high penetration and high resolution in geometry.

![Figure 2. The active fault maps on Java that have been identified and summarized in the National Earthquake Map 2017](image2)
delineation than seismic methods. This method measured the resistivity physical properties of the subsurface which the target had the high resistivity value relatively with its surrounding. Acquisition with the magnetotelluric method are conducted in numerous active fault researches like San Andreas Fault [7];[8], Kalabsha fault in Egypt [9]. Measurement data points are 12 sounding points through numerous districts at the southern East Java (Pacitan, Trenggalek, Tulungagung, Blitar, Malang, Lumajang, Jember, Banyuwangi). Density Bouguer Anomaly from USGS as the supported data for validation of the geological structure. This research is expected to provide comprehensive and more detailed information about the deformation process of the subsurface structure at the Southern of East Java as well as the phenomenon of earthquakes due to active faults seen from the subsurface resistivity distribution and its relation to other geophysical methods. Mapping the active fault became the strong activities to do because the natural hazards aspect must consider for the development of spatial planning in Indonesia.

2. Methodology
This research was conducted using a field approach, modeling the properties of resistivity and magnetism using one of the geophysical methods (Magnetotelluric). The modeling results are followed by an interpretation process that is correlated with geological data or other supporting geophysical methods. Magnetotelluric data acquisition as is illustrated in fig. 3 was carried out for 15 days from 30 June 2018 - 15 July 2018, covering districts located along Southern East Java. (Pacitan, Trenggalek, Tulungagung, Blitar, Malang, Lumajang, Jember and Banyuwangi District). Table 1 shows the retrieval data point.

| MT POINT | DISTRICT/CITY | VILLAGE      | COORDINATE X | Y          | ELEVATION (m) |
|----------|---------------|--------------|--------------|------------|---------------|
| ST01     | Pacitan       | Ngadirojo    | 9090313      | 535347    | 8             |
| ST03     | Trenggalek    | Durenan      | 9100858      | 588767    | 108           |
| ST04     | Tulungagung   | Boyolangu    | 9101443      | 596405    | 52            |
| ST05     | Blitar        | Maron-Purwokerto | 9103696      | 618442    | 118           |
| ST06     | Blitar City   | Pakunden     | 9105959      | 626343    | 163           |
| ST07     | Blitar        | Tambakan     | 9109201      | 643004    | 317           |
| ST08     | Malang        | Ngadjum      | 9102811      | 670851    | 325           |
| ST09     | Malang        | Blayu        | 9109236      | 685151    | 89            |
| ST11     | Lumajang      | Grobogan     | 9112046      | 746186    | 154           |
| ST13     | Jember        | Patrang      | 9100140      | 800691    | 132           |
| ST14     | Jember        | Kemuning Sari | 9097408      | 786431    | 159           |
| ST15     | Banyuwangi    | Wonorejo     | 9122356      | 209451    | 68            |
Figure 3. Magnetotelluric data points along the southern of East Java (yellow pin)

Figure 4 showed the configuration of data points retrieval taken for 8 hours with the radius is 20 meter which is divided into 3 variations of measurement for each station are 30 minutes for High Frequency 16 kHz, 90 minutes for Middle Frequency 4 kHz and 6 hours for Low Frequency 128 Hz.

Figure 4. Magnetotelluric Acquisition Configuration

The data is obtained in time series with the format .ats as illustrated in Figure 5. The processing flow of Magnetotelluric data in Figure 6 are done in two steps namely pre-processing and main processing. Further, time series data on magnetic fields and electric fields are transformed into frequency series using the Fast Fourier Transform (FFT) which illustrated in Figure 7.
Figure 5. Time Series Data of ST09 Point

Figure 6. ST 09 Data in Frequency Domain
3. Result
This study data was categorized into primary magnetotelluric data and secondary data. Figure 8 described the secondary data in the form of gravity data is taken from the satellite that is used for the integration process when a regional subsurface interpretation. Earthquake data is used with average Magnitude <5 near the study area with a years period of 2004 – 2017 to reinforce the results of the interpretation.

The Bouguer Anomaly distribution map showed an indication of a weak zone at the measurement station between Pacitan (ST01) - Tenggralek District (ST03) and an indication of fault zone by qualitatively looking at the distribution of Bouguer Anomaly data in Lumajang (ST11). Quantitatively, zones that are considered to be potential for weak zone structures had the density value 0-80 mGal. Meanwhile, figure 9 established the apparent resistivity versus period data profile in Transverse Electric (TE) mode as well as Transverse Magnetic (TM) mode (fig.10). The profile indicated a low resistivity value in the area between ST01 (Pacitan) and ST02 (Trenggalek) as an active fault structure.

The cross-section in figure 11 is the results of 1D inversion using Bostic Filter that formed the existence of low resistivity zone (NE-SW) at a depth of 2 km to 8 km above sea level at the area near the Pacitan District and below the Lumajang with a shallow depth of 500-1000 meter (blue) associated with a deep low resistivity zone (green) that predicted as the subduction zone system beneath the Lumajang.
Figure 8. Bouguer Anomaly Gravity Data using Free-Air Correction

Figure 9. 1D Processing of Magnetotelluric Data in Transverse Electric Mode

Figure 10. 1D Processing of Magnetotelluric Data in Transverse Magnetic Mode
4. Conclusion
This study aimed to obtain a description of the geological structure such as surface and basement faults oriented relatively parallel with Opak fault NE-SW using Magnetotelluric data. In consequence, it can be concluded from the resulting data are Gravity data method displayed the regional distribution of geological structure which low density predicted as an active fault with orientations tends to be NE-SW near the border area between Pacitan and Trenggalek as well as beneath Lumajang. Processing 1D inversion using The Bostick Method provided quantitative information with differences in resistivity contrast that indicated of faults (low resistivity zone) with orientation tend to be NE-SW between Pacitan and Trenggalek (500-8000 meter) as well as the predicted of fault in Lumajang (100-500 meter).

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