Analysis of the effect of magnetotelluric data quality improvement using rho variance and edit XPR parameters in densely populated areas

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Abstract. Magnetotelluric (MT) research was conducted to map the fault structure in the western part of East Java. The advantage of the magnetotelluric method is its deep penetration because it propagates at a low frequency so that it can detect resistivity anomalies that are thought to be faults. The measuring path of the magnetotelluric method covered the Surabaya and Gresik areas. Research conducted in densely populated areas thus it requires a noise reduction process to improve the quality of the data. Performing the robust processing with Rho Variance parameters and editing XPR is an effort to reduce noise and to improve the quality of magnetotelluric data. The robust processing result of 5 (five) sounding MT data using the Rho Variance parameter can improve the quality of magnetotelluric data by increasing the coherence value of 2.128% (MT01), 2.804% (MT02), 2.378% (MT03), 3.508% (MT04), and 3.129% (MT12). Meanwhile, the editing XPR process can increase the coherence value of 0.184% (MT01), 7.155% (MT02), 9.364% (MT03), 0.784% (MT04), and 0.628% (MT12). Escalation of coherence value by implemented the Rho Variance and Editing XPR means that two methods are sufficient effectively to raise the confidence level of MT data processing and interpretation result.

1. Introduction
Indonesia occupied a very active tectonic zone because the world's three major plates and nine other smaller plates meet each other in Indonesian territory and form complex plate meeting paths [1]. The existence of interactions between those major plates made an impact onto Indonesia as an area that is very prone to earthquakes [2]. Loss of material and fatalities as a result of the earthquake disaster were mostly caused by ignorance of a fault in an area, so there was no anticipatory measure against the movement of the fault. Therefore, active fault mapping is very necessary for the development of spatial planning in Indonesia because from now on, building construction must consider aspects of disasters, one of which is earthquakes.

Geodetic studies using the Global Positioning System (GPS) have been carried out on surface deformation measurements in Java that was identified an active extension of Flores back-arc thrust westward along 300 km throughout East Java as the Kendeng Fault [3]. The results of this study indicate a new major earthquake threat for East Java and a tsunami threat to Bali, Lombok, Nusa Tenggara, and other beaches along the Flores Sea. Information regarding near-surface faults forms the basis for studies of deformation in deeper areas. The western part of East Java, including Surabaya and its surroundings, is traversed by several geological structures including the active Lidah and Kedung Waru faults which are associated with the Tongue Anticline, the Gayangan Anticline and the Kedung Waru Anticline,
causing the western part of East Java and its surroundings to have the potential for earthquakes [4]. The National Earthquake Center (PusGeN) updated the 2017 national earthquake map with the discovery of new active faults including in the Kendeng Zone of East Java, including the Surabaya Fault, the Waru Fault, the Blumbang Fault, and the Cepu Fault. The fault moves with a displacement of about 0.05 mm with a magnitude <7 [5]. Earthquake potentials are crucial in determining earthquake hazard, therefore geometric information and location of potential sources are very important [6]. Geodetic studies have been carried out, however, data or research on fault dimensions and depths in the western part of East Java and its surroundings are still incomplete, so further research is needed.

The magnetotelluric method is a passive electromagnetic method for determining the conductivity of the earth's surface from tens of meters to thousands of meters deep [7]. The mapping of subsurface geological structures has been successfully carried out using the magnetotelluric method [8]. The existence of a geological structure is identified by the presence of a resistivity contrast that has a certain directional trend. The contrast of this resistivity value is highly dependent on the fluid or fault which are filled by the material. Based on research related to the priority of the earthquake potential on the Java Island using multi-criteria analysis of decision making [9], The Kendeng Surabaya Fault is one of the main priorities for delineating therefore this research will also depict the subsurface structures in the Surabaya, Gresik and Lamongan areas [9].

Measurement of data carried out in densely populated areas is a challenge due to noise so that it requires a noise reduction process to improve the quality of the data. Coherence analysis by performing robust processing with Rho Variance parameters and edit XPR is an effort to reduce noise and to improve the quality of magnetotelluric data. A study by comparing weighting parameters was conducted into magnetotelluric data on the island of Muna and its surroundings based on coherence analysis research which is the Rho Variance weighting parameter shows more dominating results than the other weighting parameters i.e. Robust No Weigh and Ordinary Coherency thus the Rho Variance was implemented in this study [10]. Due to the importance of further understanding about the coherence analysis, this study will examine the effects of robust processing and XPR editing as an effort to improve the quality of magnetotelluric data on geological structure investigations in East Java.

2. Methodology

2.1. Basic Principal of Magnetotelluric Method

The magnetotelluric method is one of geophysical method that utilizes passive electromagnetic waves by involving measurements of perpendicular fluctuations in the electric and natural magnetic fields on the earth's surface which can be used to determine the conductivity value of rocks beneath the earth's surface from a depth of several meters to hundreds of kilometers. Magnetotelluric measurements record two components of the electric field (E) and three orthogonal components of the magnetic field (H). The magnetotelluric method is carried out using a frequency in the range of 10-5 Hz - 103 Hz [7]. The magnetotelluric method is considered capable of mapping subsurface geological structures [11].

Figure 1 described the electromagnetic wave propagation from transmitter to receiver where the natural electromagnetic field (primary electromagnetic field) as the source of the magnetotelluric method reaches the earth with variations with time. This electromagnetic field induces ore bodies below the earth's surface, causing eddy currents (telluric currents) to arise which produce a secondary electromagnetic field. The receiver at the surface captures the total electromagnetic field as the sum of the primary electromagnetic field and the secondary electromagnetic field [12].
2.2. Fourier transformation
This process was used to convert data in the time domain into the frequency domain [13] [14]. Data from field measurements are data in the time domain. There are several parameters that cannot be analyzed in the time domain so that it requires a transformation from time domain to frequency domain to further analysis can be carried out. Fourier transform plays a role in converting time series data into frequency domain data as it explained below in equation 1:

$$x(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} X(\omega) e^{i\omega t} d\omega$$  \hspace{1cm} (1)

Where $\omega$ is the angular frequency (rad/sec), $t$ represents time (second), $x(t)$ is the function in time domain, $X(\omega)$ is the function in frequency domain; $e^{i\omega t}$ is the sinusoidal signal component.

2.3. Robust processing
Robust processing is a process used to minimize the influence of outliers (noise) by looking for the more dominant data trend direction. Data that is dominated by noise will have a small coherence value, so it can reduce the quality of the data both qualitatively and quantitatively [16]. Robust processing functions is to detect the presence of outliers in data, where outliers are data whose value is far from the overall value so that the data is given a smaller iterative weighting [17]. There are 3 parameters that can be used in the robust processing, namely [18]:

1. No Weight, data that is not weighted in consequence this data has similar type with raw data.
2. Ordinary Coherence, weighted data based on good coherence in the E field and the H field.
3. Rho Variance, is a data weighting process based on variations/changes in the rho value.

Literature study indicated that the Rho Variance weighting parameter shows more dominating results than the other weighting parameters [10] [17] [18]. Further, this research was conducted using the Rho Variance weighting parameter as well to reach the high quality of 2D magnetotelluric data result.

2.4. Crosspower selection (XPR)
Crosspower is a partial data set in the form of pairs of resistivity and phase values with the same frequency. The crosspower selection process aims to make a smooth apparent resistivity curve by selecting and sorting the most suitable data and eliminating data affected by noise [19].

2.5. Magnetoteluric Data Coherence
The coherence of magnetoteluric data is the relationship between the electric field (E) and the magnetic field (H) which is perpendicular to each other. Ideally, the coherence of magnetoteluric data will be worth one, but this is very rare, so if the data is closer to the value 1, the data will be more coherent [18] [19].
2.6. Research Flow Diagram

The general research flow diagram from acquisition data of magnetotelluric survey until its analysis is able to be seen in Figure 2 below.

![Research Flow Diagram](image)

**Figure 2.** Research Flow Diagram.

3. Study Area

This research was conducted using 5 points of magnetotelluric data covering the Surabaya and Gresik areas as displayed by Figure 3. Those points are in one straight line across perpendicular with the two major Kendeng Faults on the study area consequently those faults are captured by the magnetotelluric measurement besides other geological structures that are possible connected with the Kendeng Fault. The coordinates of the magnetotelluric data are available in Table 1. The flow of this research starts with the measurement of the magnetotelluric data which is then carried out by processing and analyzing the coherence of the data to produce quality data for subsequent purposes.
Figure 3. Magnetotelluric Method Measurement Survey in Research Fields (Surabaya-Gresik Areas).

Table 1. Measurement point coordinates.

| Name | Northing | Easting | Elevation (m) |
|------|----------|---------|---------------|
| MT01 | 9189473  | 677870  | 30            |
| MT02 | 9191356  | 678418  | 14            |
| MT03 | 9197437  | 678377  | 33            |
| MT04 | 9200255  | 678600  | 8             |
| MT12 | 9194073  | 678502  | 39            |

4. Results and Discussion

According to the percentage value which is resulted from the coherence process, it is the quantitative parameter to inform the robust quality of magnetotelluric field data. If the coherent data value is closer to 1, it is meant the survey parameters of observed data are fit properly thus we captured the subsurface anomaly with a high signal to noise ratio. When the electromagnetic wave propagated beneath the subsurface, the signal might have occurred the interference that causing noise in the measurement data. Therefore, a noise reduction process is needed to obtain high quality data. This study aims to improve the quality of magnetotelluric data by conducting coherence analysis. The coherence analysis carried out included the robust processing using the Rho Variance parameter further it is followed by XPR editing on the entire MT data. In the robust processing, there are three weighting parameters; however, in this study only the Rho Variance parameter was used. As for what is obtained as follows (Table 2).
Table 2. The results of the coherence analysis from 5 points in the study area.

| Station | Preliminary data (%) | Average (%) | Rho Variance (%) | Average (%) | XPR Edits (%) | Average (%) |
|---------|----------------------|-------------|------------------|-------------|---------------|-------------|
|         | Rho XY | Rho YX | Rho XY | Rho YX | Rho XY | Rho YX | Rho XY | Rho YX |
| MT01    | 80.917 | 83.682 | 82.3   | 79.902 | 88.954 | 84.428 | 80.955 | 88.269 | 84.612 |
| MT02    | 91.751 | 68.407 | 92.079 | 91.651 | 73.151 | 82.883 | 91.807 | 88.269 | 90.038 |
| MT03    | 77.664 | 54.387 | 76.305 | 78.208 | 58.598 | 68.403 | 79.099 | 76.526 | 77.767 |
| MT04    | 76.741 | 69.401 | 73.071 | 80.086 | 73.072 | 76.579 | 78.513 | 76.213 | 77.363 |
| MT12    | 89.219 | 78.709 | 83.964 | 91.04  | 83.787 | 87.093 | 88.627 | 86.868 | 87.747 |

The results of the coherence analysis carried out by the robust processing using the Rho Variance parameter in this area showed an increase in the average coherence value of the initial data, an increase of 2.79%. The lowest increase in the coherence value of data occurred in the MT01 data from 82.3% to 84.428% or an increase of 2.128%. The highest increase in the coherence value of data occurred in MT04 data from 73.071% to 76.579% or an increase of 3.508%.

The results of the coherence analysis carried out by the XPR editing process showed an increase in the average coherence value of the initial data, an increase of 6.418%. The lowest increase in the coherence value of data occurred in the MT01 data from 82.3% to 84.614% or an increase of 2.313%. The highest increase in data coherence value occurred in MT03 data from 66.025% to 77.767% or an increase of 11.742%. The increase in the highest coherence value can also be seen significantly in the coherence to frequency curve in the following MT03 data (Figures 4 – 6).

Figure 4. The curve of the coherence values for the Rho-XY (red) and Rho-YX (green) frequencies of the MT3 points.
Figure 5. The curve of the coherence values for the Rho-XY (red) and Rho-YX (green) points of MT3 after Robust Processing is carried out using the Rho Variance parameter.

Figure 6. The curve of the coherence values for the Rho-XY (red) and Rho-YX (green) points of MT3 after the process of XPR Editing.

The coherence curve with respect to frequency shows a significant change from 3.4 to 0.00034 Hz. In the initial data curve (Figure 5), the trend of Rho XY and Rho YX curves is very random, even at frequencies <1 - 0.004 Hz the Rho YX curve (green) has very low data coherence (<25%). In the data from Robust Processing (Figure 6), the trend of the Rho XY and Rho YX curves is better but there is still very low data coherence (<25%) at frequencies <0.215 - 0.0055 Hz. The XPR edited data shows the Rho XY and Rho YX curves have almost the same direction as a whole (Figure 7). The XPR edited
data shows a very good data coherence value compared to the initial data and the robust processing results.

The increase in the coherence value indicates that robust processing and XPR editing are very important processes in improving the quality of magnetotelluric data. The increase in the coherence value greatly affects the results of the apparent resistivity curve and the phase which tends to follow the trend. Furthermore, the data from the robust processing results will be carried out by the XPR editing process as shown below.

**Figure 7.** Apparent resistivity and phase curves of the Rho-XY and Rho-YX points MT01: (a) before XPR editing, and (b) after XPR editing.

**Figure 8.** Apparent resistivity and phase curves of the Rho-XY and Rho-YX points MT02: (a) before XPR editing, and (b) after XPR editing.
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Figure 9. Apparent resistivity and phase curves of the Rho-XY and Rho-YX points MT03: (a) before XPR editing, and (b) after XPR editing.

In the MT01 data (Figure 7), the robust processing data using the Rho Variance parameter shows the apparent resistivity and phase curves of Rho-XY and Rho-YX have a very good trend thus this data does not carry out a significant XPR editing process. This is indicated by the data coherence value after robust processing at the MT01 point of 84.428% and after XPR editing of 84.612% which only increased the coherence value of 0.184%. In the MT02 data (Figure 8), robust processing data shows the apparent resistivity and phase curves of Rho-YX (marked in red color) have a very good trend, however the apparent resistivity and phase curves of Rho-XY (represented in green) have a random trend therefore the XPR editing is required. In prior of XPR editing, the data had the coherence value of 82.883%.
Figure 1. Apparent resistivity and phase curves of the Rho-XY and Rho-YX points MT12: (a) before XPR editing, and (b) after XPR editing.

In the MT03 data, the apparent resistivity and phase curves from Rho-XY and Rho-YX have a very random trend, which is predicted contain high noise, while it is supported by the data coherence value after Robust Processing of 68.403%, we can conclude that it should have a XPR editing process. After the XPR editing process was carried out, the data coherence value increased by 9,364% thus the data coherence value became 77,767%. In addition, the apparent resistivity and phase curves of Rho-XY and Rho-YX (Figure 9) are having a better smooth trend.

In the MT04 data (Figure 10), the apparent resistivity and phase curves of Rho-XY and Rho-YX have a feasible trend however the distribution is slightly random, and then the XPR editing process is carried out. The data before the XPR editing process had a coherence value of 76,579% and after the XPR editing process was carried out it became 77,363%, there was an increase in coherence of 0.784%.

It is similar with the result of MT12 (Figure 11) which is showed the apparent resistivity and phase curves for Rho-XY and Rho-YX were having a very proper trend where the data coherence value of 87,093% and after the XPR editing process became 87,747%, it means that increased by 0.654 %.

The increase in this coherence value by doing robust processing and XPR editing shows that these two processes are very important to be implemented for reducing noise in the data, in consequence, it can improve the quality of the magnetotelluric data.

5. Conclusion
Based on the data coherence analysis that has been carried out, so the conclusion is:
1. The robust processing using the Rho Variance parameter can improve the quality of magnetotelluric data by increasing the coherence value of 2.128% (MT01), 2.804% (MT02), 2.378% (MT03), 3.508% (MT04), and 3.129% (MT12).
2. The XPR editing process can improve the quality of magnetotelluric data by increasing the coherence value of 0.184% (MT01), 7.155% (MT02), 9.364% (MT03), 0.784% (MT04), and 0.628% (MT12).

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