Identification of Soil Contamination using VLF-EM and Resistivity Methods: A Case Study

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Abstract*— Hazardous waste is a waste with properties which can pollute and damage the environment, human health, and other living things. Lakardowo is a village that is suspected of being contamination by hazardous waste derived from industrial activities. Measurements with the VLF-EM and Resistivity method were used in this study. In addition, groundwater level mapping and soil sampling in locations around the industry were conducted for the XRF test. Groundwater mapping results show that groundwater flow leads to the Northeast-South and Southwest of the industrial site. The soil samples that have been tested by XRF show the presence of heavy metals, wherein hazardous wastes generally contain various types of heavy metals that are conductive or have low resistivity values. Quantitative interpretation of VLF-EM data shows the presence of low resistivity anomalies at several measurement sites, which are suspected of having been contaminated with soil by waste. Resistivity data processing results, showing a low resistivity anomaly (≤ 3 Ω.m) located to the north (near an industrial site) and spreading towards the southwest along the measurement path. The result of a combination of quantitative interpretations of both methods, obtained, the direction of anomalous flow of hazardous waste moves southeastward and towards deeper soil coating following the direction of rock coating.

Keywords—hazardous waste, resistivity, groundwater mapping, heavy metal.

I. INTRODUCTION

Hazardous Waste is the residue of an activity containing substances or components due to its properties, concentrations and quantities either directly or indirectly can pollute or damage the environment, human health, and other living things [1]. The village of Lakardowo located in Mojokerto district of East Java is an area that is suspected to be contaminated with hazardous waste derived from surrounding industrial activities.

A Very-Low-Frequences Electromagnetic (VLF-EM) and Resistivity measurement methods are used to identify suspected hazardous waste pollution in Lakardowo. The VLF-EM is an electromagnetic method that uses radio signals from worldwide network transmitter stations; it operates in a frequency ranges between 15 and 30 kHz. Due to the easy operation of the instrument, the speed of field surveys, and low operating costs, this method is particularly well suited for a rapid initial survey and has been widely used in many geophysical studies since the 1960s [2]. On the other hand, the Resistivity method is the most widely used geophysical method for the evaluation of waste disposal sites because it is fast, reliable, affordable, and non-destructive [3]. Both methods have been successfully used to identify and evaluated landfills, leachate flow, groundwater contamination, and geo-electric layers [2]–[6].

Generally, this work is aimed to identify the value of resistivity and direction of hazardous waste distribution based on the measurement using VLF-EM and Resistivity methods in Lakardowo.

The area study is located between at longitudes 112^o 27' E – 112^o 28' E and latitudes 7^o 21' S – 7^o 23 S. The topography of Mojokerto district tends to be concave in the middle and high in the South and North. Lakardowo, the studied area, has a height of about 60 m from mean sea level [7]. Geologically, the study area is located in a West-East oriented folding zone and on the border of Rembang and Kendeng zones comprising anticlines and cyclins. Based on the geological map in Figure. 1., the study area is at the boundary or contact between Kabuh and Puncangan formation, where Kabuh formation comprises sandstone, clay inserts tuff, conglomerate, and tuff, while Puncangan formation consists of breccia, tuff sandstone inserted clay and conglomerate. The Kabuh formation is a younger rock formation compared to the Puncangan formation [8].

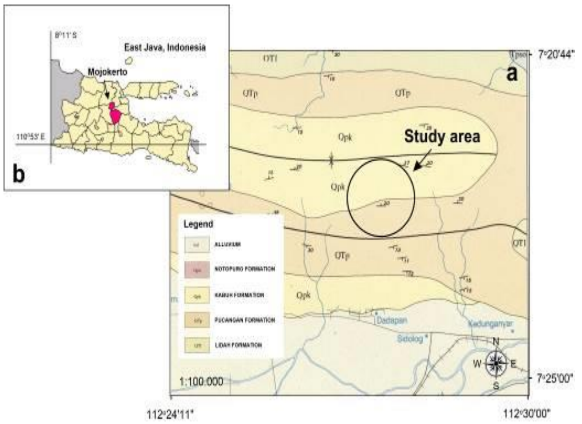

Figure 1. (a) Geological map of Mojokerto. (b) Map location of Mojokerto district, East Java, Indonesia.

II. METHOD

Data acquisition technique using VLF-EM method is done by the conventional technique with the operator facing to a transmitter. The VLF transmitter NWC located in Exmouth, Western Australia, operating at a frequency of 19.8 kHz with co-ordinates 21.816S-114.165E was selected as the source for the entire VLF survey in this study. VLF-EM data were collected along four profiles and measurements were made with a station separation of 3 m using the Scintrex Envi meter in the

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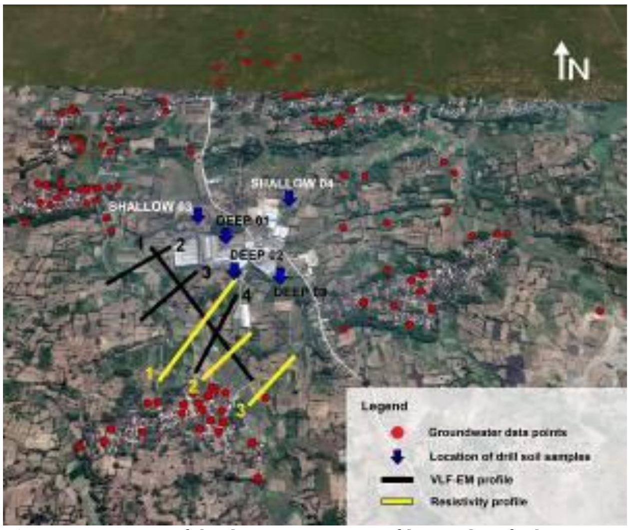

Figure 2. Location of the data acquisition profiles to identify the distribution of waste.

VLF-EM mode (i.e., measuring the ratio of the polarized magnetic field).

The lengths of the profiles vary from 270 to 651 m and are separated by 150 m to 200 m (Figure. 2.). The in-phase and quadrature data were presented as single profiles.

On the other hand, data acquisition using Resistivity method is made through the Wenner array. The acquisition was conducted on three profile, named R-1, R-2, and R-3, with the length of profiles, are 470 m, 250 m, and 250 m respectively. As shown in Figure. 2., the profiles from these two methods were collected around the industrial site in order to identify the direction of hazardous waste distribution. In addition, drill samples and groundwater data are used. Groundwater data mapping is based on the measurement of 97 well points spread around the industrial site. While the soil samples were taken at five locations of drilling with a coring depth of 5 meters up to 10 meters. The soil samples were tested for resistivity values in laboratory scale. This value will be used as the initial input to the inversion of VLF-EM data. The sample was also tested by XRF to identify the elements contained in the soil sample.

III. Results and Discussion

A. Groundwater Level Mapping and XRF Result of Soil Samples

Groundwater level data is obtained based on data of elevation wells with groundwater depth of each well from the surface. Based on Figure. 3., the lowest groundwater level is indicated by the green-blue color of the Northeast and the Southwest of the industrial site. It indicates the direction of subsurface water flow in the research area if centered at the industrial site leads to the Northeast-South and Southwest.

In the XRF results, the elements contained in the soil samples include; Iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn), Strontium (Sr), Zirconium (Zr), Barium (Ba), Rhenium (Re), Rubidium (Rb), Aluminum (Al) Silicon (Si), Sulfur (S), Phosphorus (P), Potassium (K), Calcium (Ca), Titanium (Ti), Vanadium (V) and Khrom (Cr). Figure 4 shows the test results for elements with low concentrations of the content. The high

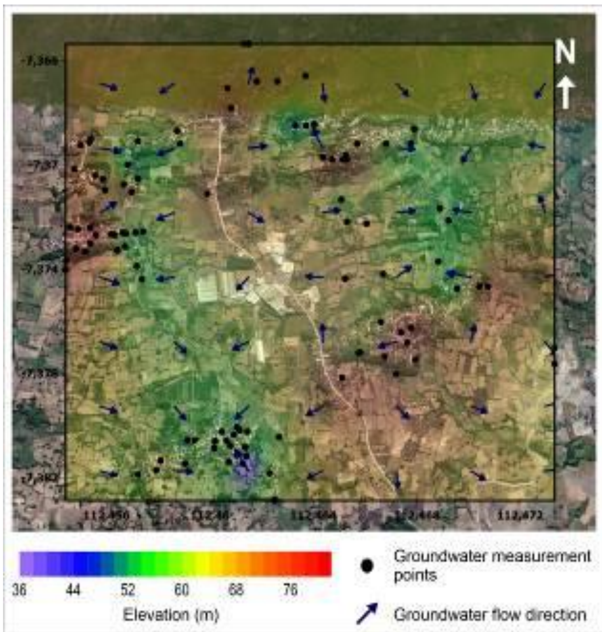

Figure 3. Groundwater elevation map in the study area.

concentration of elements, in the form of Al, Si, K, Ca, Ti, Fe, and P, are part of the clay content. XRF test results found the heavy metal Krom (Cr) and essential heavy metals namely Mangan (Mn), Iron (Fe), Zinc (Zn), Copper (Cu) and Barium (Ba). The essential heavy metals are chemical elements that are in certain amounts desperately needed by living organisms, but excessive amounts can have toxic effects [9]. In determining the threshold of the essential heavy metals, further research can be done through the result of the soil quality standard test.

B. VLF-EM and Resistivity Data Inversion

VLF-EM data is a complex data, consisting of in-phase (real part) and quadrature (imaginary part). Characteristics of the VLF-EM method that utilize low-frequency signals, causing relatively high noise in observation data. The NA-MEMD (Noise-Assisted MEMD) method is used to improve VLF-EM data observation accuracy by eliminating high-frequency noise and reducing low frequencies [10]. The inversion-processed data is NA-MEMD filtered data which has been quantitatively analyzed using Fraser and K-Hjelt filters. Inversion is done using Inv2DVLF software developed by Fernando Monteiro Santos [2]. In the process used an initial resistivity value of 3.61 Ωm. The value is the result of a laboratory scale test of soil samples and 2-dimensional inversion result of Resistivity measurement data.

Based on the surface geological conditions at the study sites, the rocks are dominated by Kabuh and Puncanga formations. Kabuh formation comprises sandstone, clay inserts tuff, conglomerate, and tiff, while Puncangan formation consists of breccia, tuff sandstone inserted clay and conglomerate. Based on the drilling of soil samples, the physical description in the study area is dominated by clay soil type, the small clay of clay, clay granulated to silt sand. The clay mineral itself is a secondary mineral that has low resistivity properties, so the 2-dimensional resistivity imaging result of each VLF-EM data profile has a value of 1-10 Ωm, as shown in Figure. 5. Based on the figure, some contour lines of

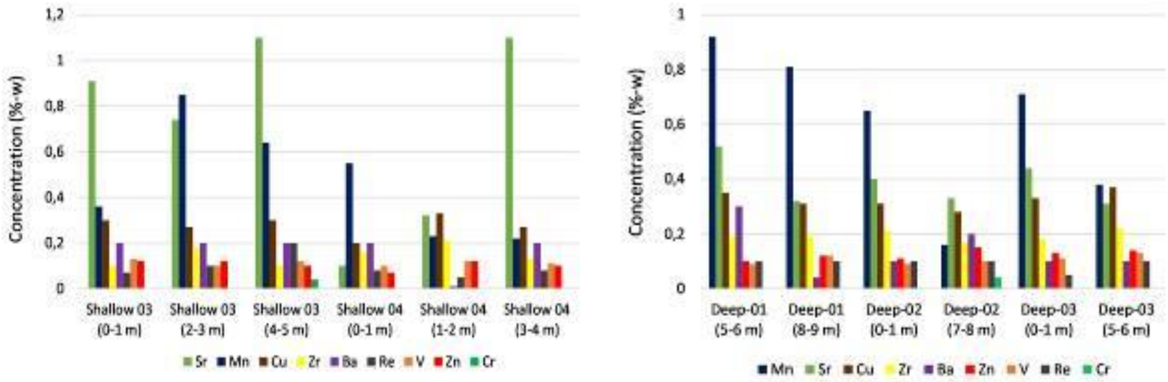

Figure 4. Distribution of XRF test result element, with low concentration value.

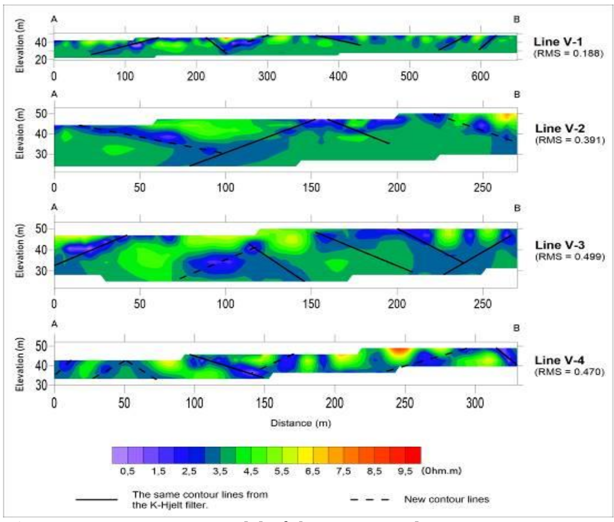

Figure 5. 2D resistivity model of the inversion data using VLF-EM. method.

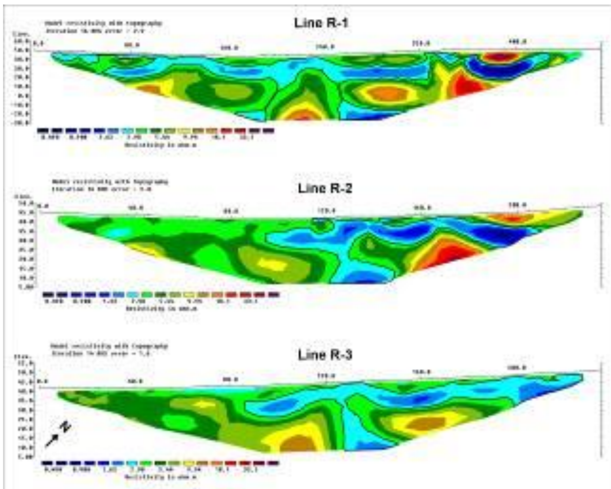

Figure 6. 2D resistivity model of the inversion data using Resistivity method.

anomalous inversion appear to correspond to the contour anomaly line of the Karous-Hjelt filter results, which

The inversion process of resistivity measurement data is done using Res2Dinv. In the inversion results, the anomalies identified as low resistivity anomalies are indicated by blue color contours, with a resistivity value of ≤ 3 Ωm, as shown in Figure. 6. In the R-1 profile, the anomaly indicated by the blue color contour is located at a depth of ± 10 meters and ± 50 meters from the surface. The anomaly is centered near the industry (from the Northeast) and flows or spreads southwestward along the R-1 trajectory. In the next two inversions, the R-2 and R-3 low resistivity anomalies are at depths of ± 10 meters and ± 35 meters from the surface. In both profiles, the anomaly does not flow along the measurement line; it is evident from the presence of rocks with higher resistivity that block the flow of low resistivity anomalies.

C. Discussion

Liquid or solid wastes are generally conductive, so they have a low resistivity. This is because the waste contains various types of heavy metals that are conductive. Hazardous wastes are containing different harmful elements such as Cr, Pb, F, As, Cu, Ba, Zn, etc., which are heavy metal elements [1], [9], [11]. It indicates that hazardous waste is conductive or has low resistivity.

In the inversion result of Resistivity measurement illustrates that rocks with high-density current densities are rocks with low resistivity values. data, an anomalous suspected hazardous waste is identified as a low resistivity anomaly indicated by a blue color contour. The low resistivity anomaly characterized by the blue color contour has a resistivity value of ≤ 3 Ω.m. The industrial location located on the Northeast (Figure. 2.) of the measurement line shows that the low resistivity anomaly is located close to the Hazardous Waste Collecting and Processing Industry, as shown in Figure. 6. In the R-1 profile the anomaly centers near the industry and flows or spreads towards the southwest along the measurement line, whereas in the next two inversions the anomaly is not spread along the line. The low resistivity anomaly distribution model is thought to be caused by the geologic structure of rocks that have a coating toward the northeast. In accordance with the geological map published by the Center for Geological Research and Development in 1992, where the study area is located in the East-West-oriented folding zone and on the border of the developing zone and the Kendeng zone comprising anticlines and cyclins (Figure. 7.) [8].

In Figure. 8. shows a 3-dimensional cross-section of the inversion of measurement data with the VLF-EM and Resistivity methods. Based on the measurements of the two methods that have been used to identify the resistivity anomaly distribution model, there are several corresponding anomalies between the 3-dimensional

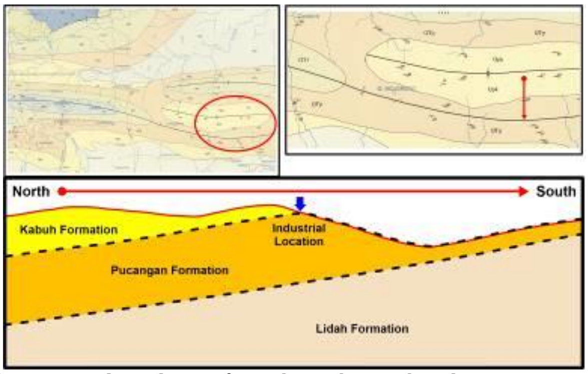

Figure 7. Geological map of Mojokerto sheet with scale 1:100.000.

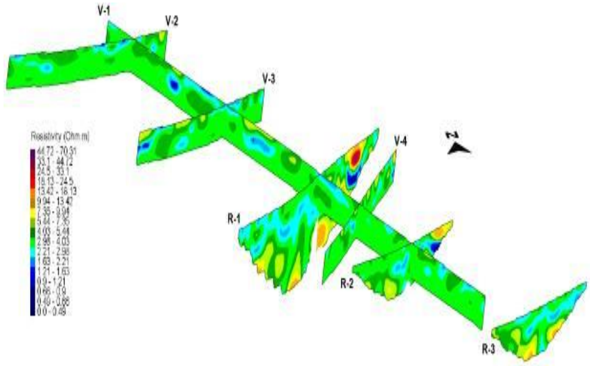

Figure 8. Model of hazardous waste distribution based on VLF-EM and Resistivity methods.

cross-sections measuring both methods. However, the distribution of resistivity anomaly flows (especially for low resistivity) is more illustrated in the results of cross-section measurements by the Resistivity method. The low resistivity marked by the blue anomaly contour shows the direction of the spread to the Southeast and Towards the deeper soil coating with a resistivity value of ≤ 3 Ω.m. The direction of the suspected distribution of hazardous waste follows the direction of the coating of the rock, as shown in Figure. 7. The Northeast - southwest trending measurement resistivity trajectory pattern makes the direction of the hazardous waste stream towards the Southeast.

IV. CONCLUSION

Based on the measurements made using the VLF-EM and Resistivity method in Lakardowo, anomalies that are suspected to be hazardous wastes are identified as low resistivity anomalies with ≤ ± 3 Ωm resistivity values that are close to the Hazardous Waste Collector and Processing Industry. XRF test results found the heavy metal Krom (Cr) and the essential heavy metals namely Mangan (Mn), Iron (Fe), Zinc (Zn), Copper (Cu) and Barium (Ba) in locations around the industry. The direction of the distribution of low resistivity anomalies suspected as hazardous waste to the Southeast and towards deeper soil coating. The tendency towards the spread of hazardous waste, caused by the direction of rock coating at the location of research to the North.

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