Identification of High Permeability Zone in Geothermal Field based on Magnetic Permeability and Dielectric Permittivity derived from SAR Polarimetric with in Situ Measurement

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Abstract. The high permeability zone has a vital role in a geothermal system and is a controlling factor for the occurrence of geothermal manifestations on the surface. This zone is often considered a weak zone associated with faults and fractures that allow geothermal fluid to pass from the reservoir to the surface. This study intends to identify high permeability zones using physical parameters in the form of relative dielectric permittivity (ε_r) and relative magnetic permeability (μ_r), which are derived from Synthetic Aperture Radar (SAR) imagery with full polarization. These parameters were extracted from SAR images using dielectric from Polarimetric Synthetic Aperture Radar (dPSAR) method. Verification is also carried out based on direct observations and measurements in the field using the Ferromaster Magnetic Permeability Meter and SM-30 Susceptibility Meter, which produce surface magnetic parameters to analyze the accuracy of dPSAR results. Based on the verification tests carried out in the manifestation zone of the Kamojang Crater, a high coefficient determination R2 around 0.82 was achieved. The dPSAR method results show that geothermal manifestation in Kamojang is characterized by high ε_r and low μ_r relatives to the surrounding area.

Keywords: *dielectric permittivity, magnetic permeability, dPSAR, geology, satellite image.*

1 Introduction

Geological structures such as faults and fractures form high permeability zones that can act as paths for thermal fluid to flow from the reservoir at depth to the surface, thus appearing as geothermal manifestation. Fractures may develop due to rock deformation during tectonic activity, such as folding and faulting. Fractures may also develop around intrusive bodies, which develop during the intrusion of igneous rock into the surrounding rock (Suryantini and Wibowo in [1]). Thermal fluids migrate from the reservoir to the surface due to weak zone then appears as manifestations of the subsurface systems. Weak zones with high permeability due to the presence of geological structures can control the presence of geothermal features on the surface (Saepuloh, et al. in [2]). The resulting study by Soengkono in [3] shows a close spatial relationship between permeable zone and high-temperature geothermal systems, and it has been proven in many geothermal explorations and exploitations that the high permeability zone is a significant drilling target to find productive wells. Thus, identifying and delineating high permeability zone in geothermal areas is essential for geothermal exploration and exploitation.

High permeability zone is often analyzed through lineament based on optical satellite image. It is identified through lineament density which is the number of lineament pattern presences in an area (Agung, et al. in [4]). At the same time, erosion and deposition of minerals carried by thermal water or alteration may cover faults and fractures on the surface. The appearance of the surface manifestations such as ground alteration, mineral deposition (e.g., silica sinter), and the occurrence of thermal springs and fumaroles thus reflects the faults and fracture that host fluid flow (Suryantini and Wibowo in [1]). To overcome these obstacles, another approach is needed to add more information in identifying high permeability zones. Hence, in this study, dielectric from Polarimetric Synthetic Aperture Radar (dPSAR) method is applied to obtain physical parameters of the surface related to the high permeability zone.

2 Research Method

Thermal fluid activity may change the physical properties of the host rock. Thus mapping physical properties of the surface can be done to detect those changes. The physical properties that may be affected by thermal fluid activity are relative dielectric permittivity (ε_r) and relative magnetic permeability (μ_r) that can be obtained by direct measurement on the field, which may require quite a lot of time and resources. These εr and μr parameters are also obtainable from SAR images, although it requires a somewhat complex process and selecting the right satellite image. Dielectric from Polarimetric Synthetic Aperture Radar (dPSAR) method is applied to SAR imagery to derive relative dielectric permittivity (ε_r) and relative magnetic permeability (μ_r) (Saepuloh, et al. in [5]). In this study, the dPSAR inversion process was carried out to obtain ε_r and μ_r parameters, which were then validated with direct field measurement data.

The dPSAR method in this study uses Polarimetric Synthetic Aperture Radar (PolSAR) satellite imagery which is Advanced Land Observing Satellite 2 (ALOS -2) Phased Array type L-band Synthetic Aperture Radar (PALSAR-2). ALOS is a satellite launched by Japan Aerospace Exploration Agency (JAXA) on 24 January 2006. The PALSAR-2 aboard the ALOS is a Synthetic Aperture Radar (SAR), which emits microwave and receives the reflection from the ground to acquire information. ALOS-2 PALSAR-2 imagery is used on the dPSAR in this study because it operates on L-band. It has good penetration ability and is suitable for use in densely vegetated tropical areas like Indonesia. The research study area is located at Kamojang, Jawa Barat (Figure 1).

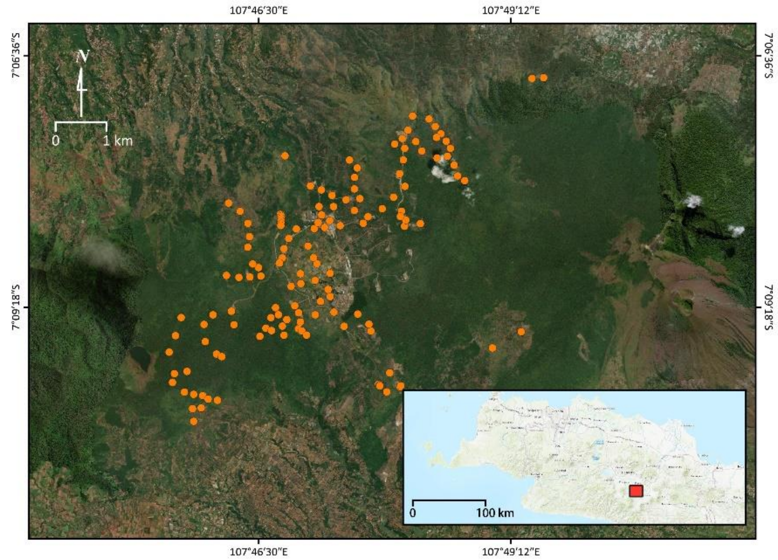

Figure 1 Research study area is located around Kamojang geothermal field, with Mount Guntur on the east side. Locations of direct field measurement are marked by red points.

2.1 Obtaining dielectric permittivity and magnetic permeability

Dielectric permittivity (ε_r) and magnetic permeability (μ_r) from polarimetric SAR images are obtainable using dPSAR method. Dielectric permittivity is the degree to which a certain medium resists the flow of electricity divided by the degree to which free space resists such a flow, it is also defined as the ratio of the electric displacement to the field strength. Magnetic permeability is a property that allows magnetic lines of force to pass through the material, in short, it can also be defined as magnetization capability. Electromagnetic waves emitted by the satellite interact with surface material on earth and then the reflected waves are received back by the satellite sensor. The inversion process is carried out to obtain the solution to the reflectivity equation of the material using the Small Perturbation Model of Backscattering (SPMB). The equations of the SPMB model (Fung and Chen in [6]) used in this study can be written as follows:

$$\sigma^0_{HH} = \frac{(4k^4 h_0^2 \cos^4\theta_i)\omega(x,y)\left|(\mu_r-1)\left[(\varepsilon_r\mu_r-\sin^2\theta_i)+\mu_r\sin^2\theta_i\right]+\mu_r{}^2(\epsilon_r-1)\right|^2}{\left[\pi\left(\mu_r\cos\theta_i+\sqrt{\epsilon_r\mu_r-\sin^2\theta_i}\right)^4\right]} \quad (1)$$

$$\sigma_{VV}^0 = \frac{(4k^4h_0^2\cos^4\theta_i)\omega(x,y)\left|(\varepsilon_r-1)\left[\left(\varepsilon_r\mu_r-sin^2\theta_i\right)+\varepsilon_r sin^2\theta_i\right]+\varepsilon_r{}^2(\mu_r-1)\right|^2}{\left[\pi\left(\varepsilon_r\cos\theta_i+\sqrt{\varepsilon_r\mu_r-sin^2\theta_i}\right)^4\right]} \quad (2)$$

$$\varepsilon_r = \frac{\cos^2\theta_i\sqrt{\sigma_{HH}^0\pi}}{(8k^4h_0^2\cos^4\theta_i)\omega(x,y)} + \frac{\cos^2\theta_i}{2} \quad (3)$$

$$\mu_r = \frac{\left((4k^4h_0^2\cos^4\theta_i)\omega(x,y)(\varepsilon_r+\sin^2\theta_i)+\varepsilon_r\sqrt{\sigma_{HH}^0\pi}\right)^2+\sigma_{HH}^0\pi\,4\cos^2\theta_i\sin^2\theta_i}{4\varepsilon_r\,\sigma_{HH}^0\pi\cos^2\theta_i} \quad (4)$$

SPMB can be used to obtain the physical properties and geometrical properties of the surface. To obtain physical properties, we use parallel polarization coefficient (HH and VV) which is stated in Eq. (1) and (2), where k is wavenumber $(2\pi/\lambda)$, h_0 is surface roughness, θ_i is the local incident angle, ω is surface spectral density, ε_r is relative dielectric permittivity and μ_r is relative magnetic permeability. To obtain ε_r and μ_r, Eq. (1) and (2) are modified by substitution method (Arvianto in [7]) into simpler form as in Eq. (3) and (4).

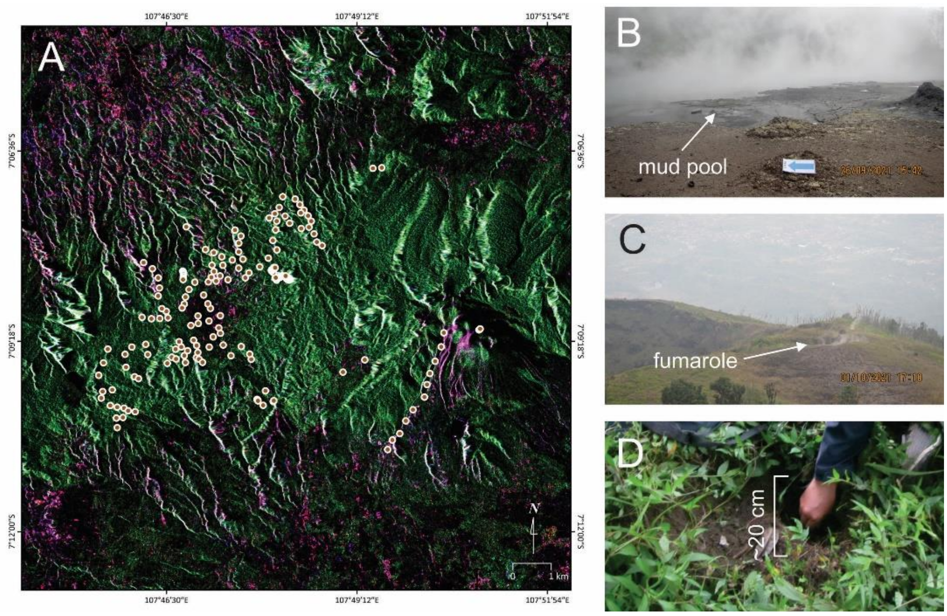

Figure 2 Field measurement location on ALOS-2 PALSAR-2 satellite image composite of HH-HV-VV polarimetric on R-G-B (A), mud pool manifestation at Kamojang (B), fumarole manifestation at Mt. Guntur (C), and field data measurement technique(D).

The result of dPSAR method is also validated by direct field measurement to find out the effectiveness of this method. Magnetic permeability obtained from field measurements was measured using a Ferromaster Magnetic Permeability Meter instrument. A total of 125 field data were obtained which were spread randomly and evenly in the research location (Figure 2-A), including around the Kamojang and Guntur manifestation (Figure 2B and 2C). Magnetic measurements were carried out on a surface that had been perforated about 20 cm, to minimize local factors present on the ground surface (Figure 2-D).

2.2 Result Validation

The inversion process of the dPSAR method on the ALOS-2 PALSAR-2 image obtains surface physical parameters in the form of relative dielectric permittivity (ε_r), relative magnetic permeability (μ_r), and surface roughness (h_0). In this study, validation was carried out on the results of dPSAR magnetic permeability using direct field measurement data. Magnetic permeability measurements were carried out in-situ using Ferromaster Magnetic Permeability Meter. The magnetic permeability of dPSAR is the final result in the sequence of the inversion process. Thus, the validation results are expected to also represent the parameters that have been obtained previously, including the dielectric permittivity parameter.

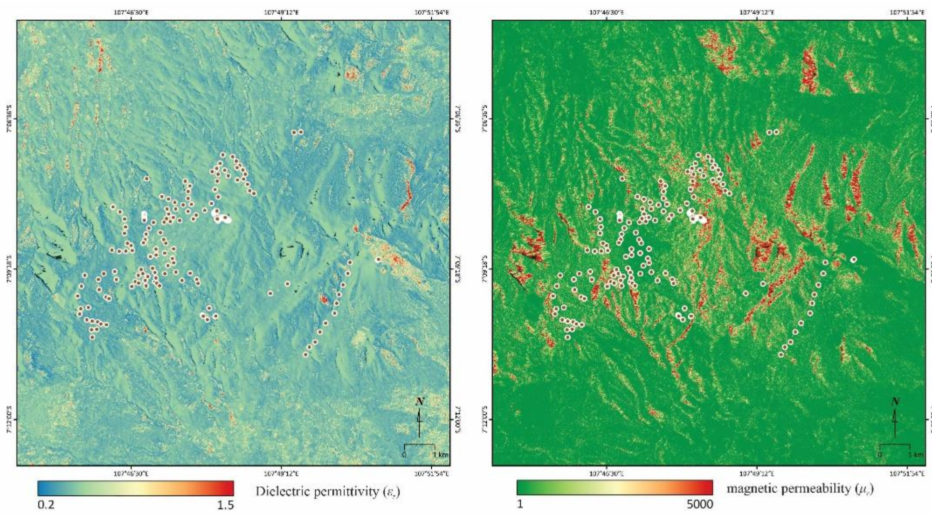

Figure 3 Results of dPSAR inversion method. Relative dielectric permittivity distribution map (left) and relative magnetic permeability distribution map (right). Direct field measurement location is marked with red dots.

Relative magnetic permeability (μ_r) obtained from the dPSAR inversion method (Figure 3) showed a value range of 1 - 5000, while μ_r obtained from direct measurements in the field had a value range of 1.00 - 1.05. The range of values obtained from field measurements has a smaller scale than the dPSAR results, this is because the specifications of the instruments used are different. However, the results of the two have relatively similar patterns. Both of these results indicate low anomalies around the manifestations in the crater of Kamojang and Gunung Guntur which indicate a high permeability zone.

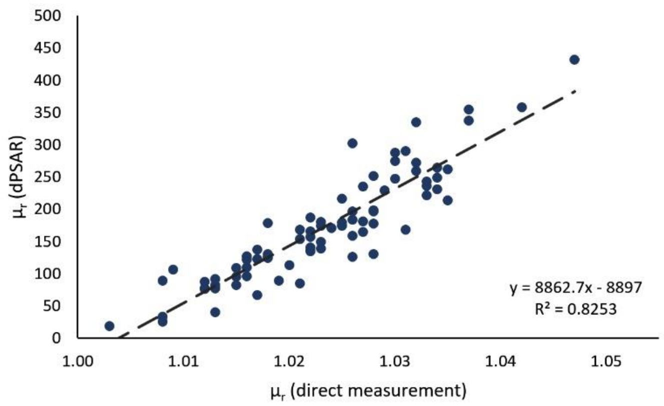

Figure 4 Cross-plot between μ_r obtained from field measurement with dPSAR which shows a positive correlation in linear regression with a coefficient of determination of 0.82.

The coherence test between μ_r obtained from the dPSAR inversion method to μ_r obtained from in-situ measurements showed the coefficient of determination R^2 from the cross plot of two variables was 0.82. The data distribution shows a fairly high linear correlation of the 95 data pairs. This shows that the parameters obtained from the results of the dPSAR inversion method have a fairly high level of accuracy against the actual conditions on the surface. Improved algorithms and image processing methods need to be continued to obtain more accurate results.

3 Results and discussion

High permeability zones are important features in geothermal systems. Structures and fractures in this zone can act as thermal fluid paths from reservoirs at depth to shallower depths to the surface and appear as geothermal manifestations. In addition, it can also act as a recharge area that allows meteoric water to enter the geothermal system cycle. The high permeability zone is characterized by high dielectric permittivity (ε_r) and low magnetic permeability (μ_r) relatives to the surrounding area. Due to its high permeability, it allows more fluid to be accommodated so that it may have high water content, hence increasing the value of the dielectric permittivity of the high permeability zone. When rocks are saturated with water, their dielectric permittivities can increase drastically. This is because water has a relative permittivity of 80, which is much higher than the relative permittivities of rock-forming minerals. As a result, the bulk dielectric permittivity of a rock increases as pore water saturation increases (Fitterman in [8]). In geothermal systems, thermal fluid activity can cause changes in the physical character of the host rock. The process of alteration of clay minerals and the degradation of the existing magnetic minerals causes a decrease in the magnetic properties of the rocks it passes through. Existing minerals in the rock that are in contact with thermal fluids will experience changes in chemical composition which generally form altered minerals such as clay, thereby reducing the magnetic value of the original mineral (Townley, et al. in [9]).

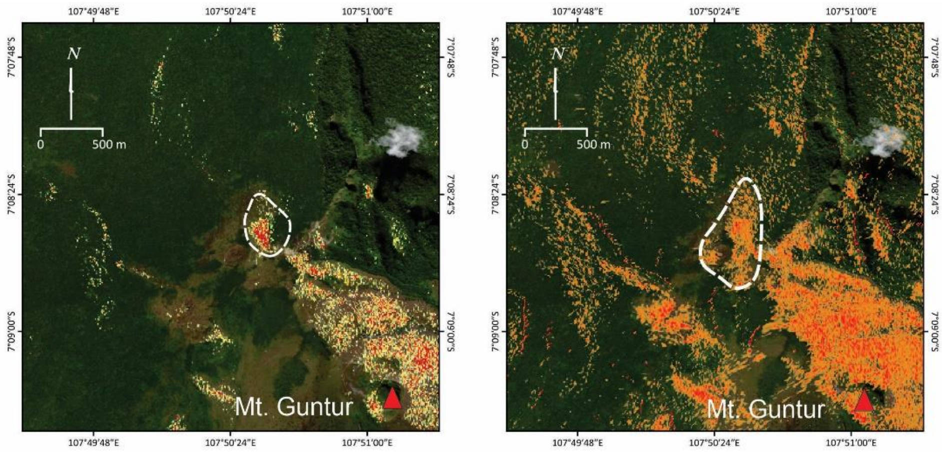

Figure 5 Possible high permeability zone detected by dPSAR methods which is located at North-West of Mt. Guntur. High dielectric permittivity is colored with red (left) and low magnetic permeability is also colored with red (right). Area of interest is deliniated with white dotted lines.

At the known manifestation locations, based on the dPSAR inversion, a high anomaly was obtained in the dielectric permittivity value and a low anomaly in the magnetic permeability value in the manifestation of the Kamojang crater and also Guntur crater. This indicates that the manifestation zone, which is a high permeability zone, has high water content and a decrease in magnetic properties due to thermal fluid which is reflected in the value of its dielectric permittivity (ε_r) and magnetic permeability (μ_r). Based on the coherence value between field measurements and the high dPSAR parameter (0.82), it is possible for dPSAR analysis to be applied to a wider area to be able to cover the under-explored area. On the west side of Mt. Guntur, the results of the dPSAR inversion show the same pattern characteristics as the previously known manifestations (figure 5). This zone has a high dielectric permittivity (ε_r) and is in stark contrast to its surrounding area, and has a low magnetic permeability (μ_r) as well.

4 Conclusion

The coherence test between μ_r obtained from the dPSAR inversion method to μ_r obtained from in-situ measurements showed the coefficient of determination R^2 from the cross plot of two variables was 0.82. This shows that the parameters obtained from the results of the dPSAR inversion method have a fairly high level of accuracy against the actual conditions on the surface. The high permeability zone is characterized by high dielectric permittivity (ε_r) and low magnetic permeability (μ_r) relatives to the surrounding area. Due to its high permeability, it allows more fluid to be accommodated so that it may have high water content, hence increasing its dielectric permittivity value. Thermal fluid activity can cause changes to the physical character of the host rock. The process of alteration of clay minerals and the degradation of the existing magnetic minerals causes a decrease in the magnetic properties of the rocks it passes through. Based on the dPSAR inversion, a high anomaly was obtained in the dielectric permittivity value and a low anomaly in the magnetic permeability value in the manifestation of the Kamojang crater and also Guntur crater. A possible high permeability zone is detected by dPSAR methods which is located at North-West of Mt. Guntur, it has the same pattern characteristics as the previously known manifestations. Further investigation of the area of interest is needed to obtain more detailed information on the potential of geothermal resources.

5 References

[1] Suryantini & Wibowo, H.H., *Application of Fault and Fracture Density (FFD) Method for Geothermal Exploration in Non-Volcanic Geothermal System; a Case Study in Sulawesi-Indonesia*, Proceedings World Geothermal Congress, 2010.

[2] Saepuloh, A., Haeruddin. H., Heriawan, M.N., Kubo, T., Koike, K. & Malik, D., *Application of Lineament Density Extracted from Dual Orbit Synthetic Aperture Radar (SAR) Images to Detecting Fluid Paths in Wayang Windu Geothermal Field (Wes Java, Indonesia)*, Geothermics, **72**, pp. 145-155, Mar. 2018.

[3] Soengkono, S., *Assessment of Faults and Fractures at The Mokai Geothermal Field, Taupo Volcanic Zone, New Zealand*, Proceedings World Geothermal Congress, pp. 1771-1776, 2000.

[4] Agung, Y.Z., Haryanto, A.D., Hardiyono, A., Setiawan, D.L & Suleman, W.A., *High Permeability Zone on Geothermal Manifestations Using Fault*

Fracture Density in Sembalun Area, Lombok, Journal of Geological Sciences and Applied Geology, **5**, pp. 24-30, Aug. 2021.

[5] Saepuloh, A., Army, E.K. & Hilman, Z., *Pemetaan Permeabilitas Magnetik Permukaan Berbasis Citra SAR Polarimetrik dengan Pengukuran In-Situ di Lapangan Gunung Api*, Riset Geologi dan Pertambangan, **30(2)**, pp. 131-142, Dec. 2020.

[6] Fung, A.K. & Chen, K.S., *Microwave Scattering and Emission Models for Users*, Artech House, 2010.

[7] Arvianto, D., *Aplikasi dan Verifikasi Geologi Metode Polarimetric Synthetic Aperture Radar (PolSAR) untuk Identifikasi Sebaran Mineral Monasit di Kabupaten Bangka, Bangka Tengah dan Bangka Selatan*, Thesis, Fakultas Ilmu dan Teknologi Kebumian, Institut Teknologi Bandung, Bandung, 2021.

[8] Fitterman, D.V., *Tools and techniques: Active-Source Electromagnetic Methods*, Treatise on Geophysics, Gerald Schubert, ed. 2, Elsevier, pp. 295-333, 2105.

[9] Townley, B., Ropperch, P., Oliveros, V., Tassara, A. & Arriagada, C., *Hydrothermal Alteration and Magnetic Properties of Rock in The Carolina de Michilla Stratabound Copper District, Northern Chile*, Miner Deposita, **42**, pp. 771-789, May 2007.