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A Novel Combination of Multi-Sensor Remote Sensing and Geostatistics for Advanced Potential Mapping of Geothermal Resources over Java Island, Indonesia

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1. Introduction

Spatial priority analyses based on multi-sensor remote sensing data provide comprehensive information of ground surface condition. For geothermal exploration, these analyses are crucial not only to detect the new potential areas but also to predict the extension areas surrounding a geothermal power plant, however it has a limitation in tropical conditions, which have a high precipitation and dense vegetation. To overcome this problem, this study proposed a Weighted Fuzzy Logic method termed as WFL to obtain spatial priority rank from multiple variables simultaneously. This method is different with classical logic theory in which data set have only two-logic values: false (=0) and true (=1). The WFL is a decision technique to calculate spatial rank of geothermal potential (Saepuloh et al. 2013). The membership functions can be derived from multiple values of datasets. In this study, we used datasets from LANDSAT Operational Land Manager (OLI), ASTER thermal infrared (TIR), digital elevation model (DEM) data, and geophysical data such as gravity data and aeromagnetic data. The main reason for this study is to assist and support the Indonesian government effort to optimize the utilization of geothermal energy, especially for electricity generation of 7,242 MW by 2030.

2. Data and Methodology

2.1 Study area and data

This research focuses on Java Island as its study area. It is geographically located between E105^{O}7'-114^{O}37' and S5^{O}48'-8^{O}37' and has approximately 138,800 km^2 (Figure1). The island has the largest installed power generation capacity in Indonesia with total capacity 10,572 MW or 14.5% of the power generation in Indonesia (Sidik and Harmoko, 2022). Two data types from different sensors were used in this study: 14 scenes from visible near infrared (VNIR-SWIR) of Landsat (OLI), 114-night scenes from (TIR) of ASTER, gravity data, aeromagnetic data, and DEM data. The raw data of Landsat OLI and ASTER TIR was corrected geometrically and atmospherically to radiance at sensor before converting to reflectance and thermal radiance data.

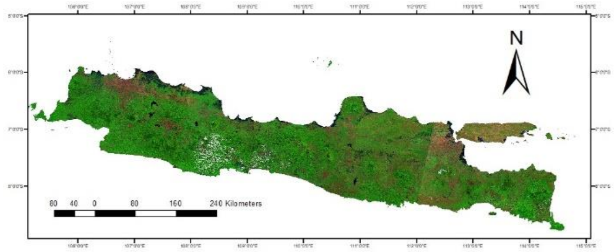

Figure 1. Satellite Imagery covering the study area.

In addition, the DEM data was used to detect the linear feature density related to geological structure, the gravity observation data was used to analyzing bouguer anomaly, and aeromagnetic data was used to detect magnetic properties of the surrounding rocks around the volcano mountain at study area.

2.2 Methodology

Because the optical sensor is affected strongly by the atmospheric condition, a Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) was used to remove the effect of atmospheric propagation (Kaufman et al., 1997). After the atmospheric artifact was removed, the Spectral Angle Mapper (SAM) classification was used to detect the distribution of clay mineral. The six spectra of clay minerals from measurements with spectrophotometer were used as referenced spectra data (Fig. 2). These spectra were used as input for the SAM classification.

To assess vegetation condition, the VIGS (Vegetation Index considering Greenness and Shortwave infrared) algorithm by (Hede et al., 2015) was applied. This index is aimed at wide availability to general multispectral satellite imagery by integrating visible green, red, near infrared, and shortwave infrared. Furthermore, the land surface temperature (LST) map was obtained from the separation of temperature and emissivity of ASTER TIR data.

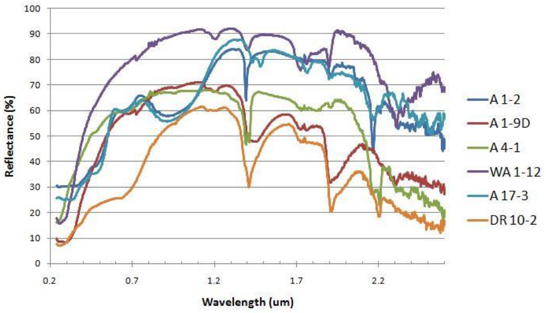

Figure 2. Spectral reflectance of clay minerals.

3. Result and Discussion

Following (Saepuloh et al., 2012) to compute the spatial rank or degree of evidence (μ_ω), the ten memberships were transformed to fuzzy membership by the following equation:

$$\mu(x) = \left(\frac{x - min}{max - min}\right) \tag{1}$$

Then, the ten memberships could be integrated using WFL methods, as illustrated by the following equation:

$$\mu_\omega = \frac{\left(\sum_{j=1}^{m}(1 - \prod_{i=1}^{m}(1 - \mu_i)) \times \omega_j\right)^{\gamma}}{\left(\sum_{j=1}^{m}\prod_{i=1}^{m}\pi_i\,\omega_i\right)^{(1-\gamma)}} \tag{2}$$

where m denotes the number of datasets, μ_i represents the fuzzy membership function, ω_i is the weighted function, and γ is a selected constant (=0.975). By integrating these datasets, comprehensive geothermal prospect zone maps were generated as shown in Figure 3.

Based on generated geothermal prospect map reveal a distinct pattern of geothermal manifestations predominantly clustered in mountainous regions with high vegetation stress and low magnetism. Although the surface temperature was medium to high, the mineral mapping confirmed that the existence of the clay minerals, silica sinter, and sulfur was supposed to be an indication of alteration zones. Furthermore, a closer examination of the pattern of fault lines indicates a high likelihood of encountering geothermal manifestations in the center and southern part of Java Island. The similarities in faultline formations, low magnetism value, and high vegetation stress between this region and the middle area further support the prospects of significant geothermal resources in these areas.

4. Summary

Combining the fuzzy theory and geostatistics is superior for estimating the rank of membership by interpolating the unobserved point using surrounding observed point and weight criterion. However, the approach has limitations, including false positive due to topographic effects, resolution issues, surface orientation, and limited pixel sampling areas, as there are few bare land areas.

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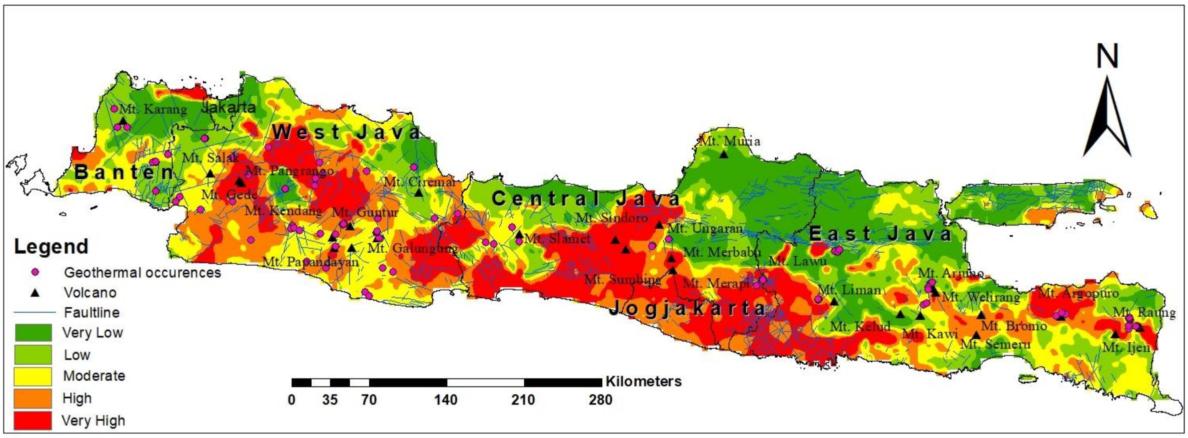

Figure 3. Geothermal prospectivity map through Weighted Fuzzy Logic and data integration.