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Integration of a satellite image with geologic and topographic information for delineating geothermal potential areas in East Java Island (Indonesia)

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1. Introduction

Indonesia's unique location at the convergence of multiple tectonic plates has made it a prime candidate for geothermal energy utilization, with a total geothermal potential estimated at 28,910 mW, drawn from 312 fields across several islands (Pambudi, 2018). Surface manifestations such as hot springs, mud pools, hydrothermal alteration, fumaroles, and sinter silica indicate potential geothermal energy sources. These manifestations reveal higher temperatures than their surrounding environments, making them easily identified as anomalies. The main objective of this research project is to identify the thermal anomalies and utilize the Landsat 8 OLI/TIRS imagery to identify areas with geothermal manifestations as indicators of geothermal activity in East Java Indonesia. Combining TIR (Thermal Infrared) remote sensing with geological analysis and understanding geothermal mechanisms is an accurate and efficient approach to geothermal area detection (Qin et al., 2011). The main reason for this study is to assist and support the Indonesian government's efforts to optimize the utilization of geothermal energy, especially for electricity generation of 7,242 mW by 2025.

2. Study Area and Methodology

2.1. Study area and data

This research focuses on the province of East Java as its study area. It is geographically located between 111°0' - 114°4' East Longitude and 7°12' - 8°48' South Latitude and has an area of approximately 48,040 Km^2 (Figure 1). In general, East Java can be divided into two main parts, namely mainland East Java with a larger proportion of almost 90% of the entire area of East Java Province, and the Madura Islands area which is only about 10%. The province has the largest installed power generation capacity in Indonesia with a total of 10,572 mW or 14.5% of the power generation in Indonesia (Sidik and Harmoko, 2022). The datasets used in this method are multisensor image data from Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS), geological data, and digital elevation model (DEM) data.

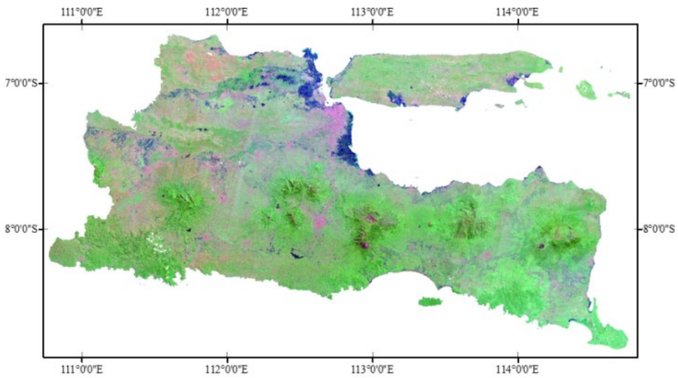

Figure 1. Landsat-8 image covering the study area

2.2. Methodology

The analysis of the study area's land cover, vegetation density, and land surface temperature (LST) relied on data obtained from the Landsat 8 satellite. The land cover was determined by subjecting the satellite image to a classification process, which utilized a supervised method employing a support vector machine module. To assess vegetation density, the NDVI (Normalized Difference Vegetation Index) algorithm was applied. This algorithm calculates the index by comparing the near-infrared and red bands of the satellite image, enabling the quantification of vegetation density based on the variation between these spectral bands.

Furthermore, the land surface temperature map was generated using specific algorithms, namely the LST algorithm and the LSE (Land Surface Emissivity) algorithm, the researchers were able to detect temperature anomalies that may indicate the presence of geothermal energy. These algorithms utilized the thermal information extracted from band 10 and band 11 of the satellite image, however, not all of these anomalies are indicators of geothermal energy. The above research flow is summarized in Figure 2.

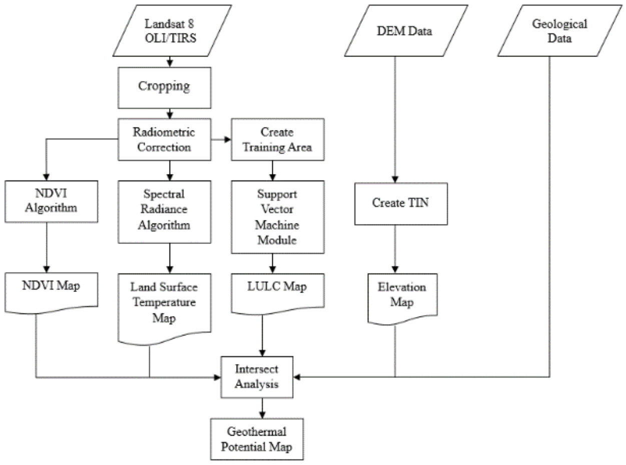

Figure 2. Research flowchart to investigate the geothermal potential area.

3. Results and Discussion

The collected data were processed into thematic maps with the projection system Universal Transverse Mercator (UTM) zone 49S. Geothermal potential zone maps were delineated by employing a combination of key factors and data overlays. These factors include land use and land cover (LULC), land elevation, normalized difference vegetation index (NDVI), and land surface temperature (LST). By integrating these datasets, along with the combination of fault line data, lineament density, and geothermal manifestation locations, comprehensive geothermal potential zone maps were generated as shown in Figure 3.

Based on generated geothermal potential zone map reveals a distinct pattern of geothermal manifestations predominantly clustered in mountainous regions. Notable locations exhibiting geothermal activity include Mt Lawu, Mt Arjuno, Mt Pandan, Mt Argopuro, and Mt Wilis. These mountainous areas emerge as hotspots of geothermal potential, suggesting favorable conditions for geothermal resources exploration and development. Furthermore, a closer examination of the density pattern of fault lines indicates a high likelihood of encountering geothermal manifestations in the southwestern part of East Java Province. The similarities in fault formations between this region and the northwest area, as well as around Mt Arjuno-Welirang, further support the prospects of significant geothermal resources in these areas. These findings provide valuable guidance for future geothermal exploration efforts, highlighting specific regions within East Java Province that hold promising prospects for future geothermal energy development.

4. Summary

Even though TIR remote sensing is undoubtedly a valuable tool, it does possess certain limitations when it comes to geothermal resource exploration and monitoring. Consequently, relying exclusively on TIR remote sensing would prove inadequate for effectively assessing and monitoring geothermal resources. It becomes imperative, therefore, to integrate additional techniques and methodologies that can complement and augment the capabilities of TIR remote sensing. By doing so, a more comprehensive and precise assessment of geothermal reservoirs can be achieved. Incorporating diverse approaches will contribute to a more holistic approach to geothermal exploration and monitoring, leading to improved decision-making and resource management in this study.

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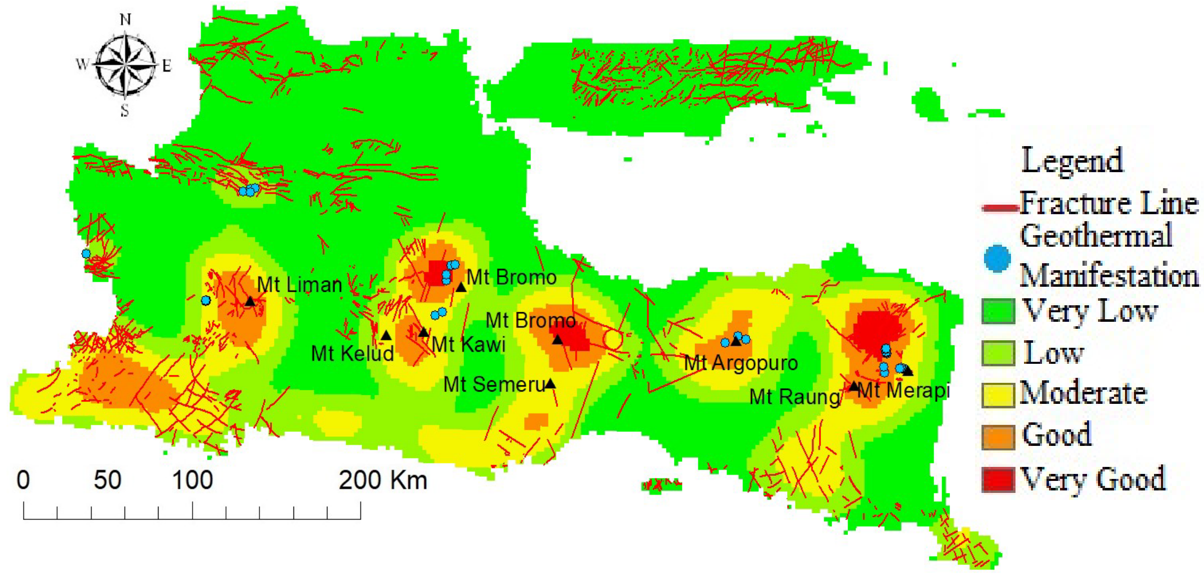

Figure 3. Potential geothermal zone map.