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Identification of Remote Sensing Data: NDVI, LST, and LULC on Geothermal Manifestations in Bondowoso Regency

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Abstract: The increasing energy demand in Indonesia encourages the exploration of alternative energy sources, including geothermal energy. Bondowoso Regency, particularly the Blawan area, holds significant geothermal potential that remains underutilized. This study analyzes the relationship between Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), and Land Use Land Cover (LULC) using Landsat 8 imagery processed through Google Earth Engine. Spatial data of LST, NDVI, and LULC were extracted, visualized, and interpreted to identify geothermal manifestation areas. The results show that geothermal manifestations are indicated by high LST values (above 35°C), low NDVI values (sparse vegetation), and specific land use patterns, especially in the northeastern part of Bondowoso. The integration of LST, NDVI, and LULC enables more accurate identification of geothermal potential. The study concludes that remote sensing-based analysis is effective for detecting geothermal manifestations and supports more optimal geothermal resource mapping, exploration, and management, contributing to the sustainable development of renewable energy in the region.

Keywords: Geothermal manifestations; LST; LULC; NDVI; Remote sensing

Introduction

The growing population of Indonesia, which continues to increase each year, has resulted in a significant rise in energy consumption (Cahyono & Hakimah, 2019). Energy is a fundamental requirement in human activities; however, the majority of energy needs in Indonesia are still met by fossil fuels such as oil and coal. The increase in energy consumption due to population growth has depleted fossil fuel reserves in nature, prompting the government to develop alternative energy sources. One with great potential is geothermal energy (Raehanayati et al., 2013).

Bondowoso Regency in East Java Province is known to have significant geothermal energy potential (Afandi et al., 2018). Geothermal energy is a renewable energy source that can provide a clean and sustainable energy alternative (Noywuli, 2024). However, the exploration and utilization of this energy require accurate methods for identifying and mapping geothermal manifestations (Darmawan et al., 2021).

Remote sensing has become an essential tool in geospatial mapping and the efficient collection of large-scale data. In geothermal research, several parameters that are commonly used include Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), and Land Use/Land Cover (LULC) (Sagita et al., 2022). LST measured using satellite sensors, provides indications of temperature anomalies related to subsurface geothermal activity (Izah et al., 2023). NDVI measures vegetation conditions and can indicate changes in vegetation due to geothermal activity (Farbo et al., 2024). Meanwhile, LULC describes land use, which is crucial for understanding the geographical and ecological context of the research area

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and supporting environmental management around geothermal manifestations (Lou et al., 2024).

Several previous studies have been conducted, such as the research by Romaguera et al. (2018), which evaluated the LST component in detecting geothermal anomalies. They found that areas with steep topography often produce high LST values as false positives, indicating that additional supporting data is needed to enhance the accuracy of the analysis. Another study by Syawalina et al. (2022) showed an inverse relationship between LST and NDVI, where dense vegetation can absorb thermal energy from geothermal sources and lower the recorded temperature.

The novelty of this research lies in the simultaneous integration of LST, NDVI, and LULC remote sensing data for geothermal manifestation identification, providing a more comprehensive and accurate analysis compared to prior studies that examined these parameters separately. However, there has been no comprehensive study that connects NDVI, LST, and LULC with geothermal potential. Therefore, this research aims to identify and analyze LST, NDVI, and LULC remote sensing data to better understand the geothermal manifestations in Bondowoso Regency. It is hoped that the results of this study will support the effective exploration and utilization of geothermal energy and contribute to sustainable natural resource management in the region.

Method

Research Location

This research was conducted in Bondowoso Regency, located in East Java Province, Indonesia, with geographical coordinates between 113°48'10" to 113°56'41" East Longitude and 7°50'10" to 7°56'41" South Latitude (Ardiansyah et al., 2021). The research timeframe covers the most recent year, 2023, to obtain representative and up-to-date data. The research area is illustrated in Figure 1 below.

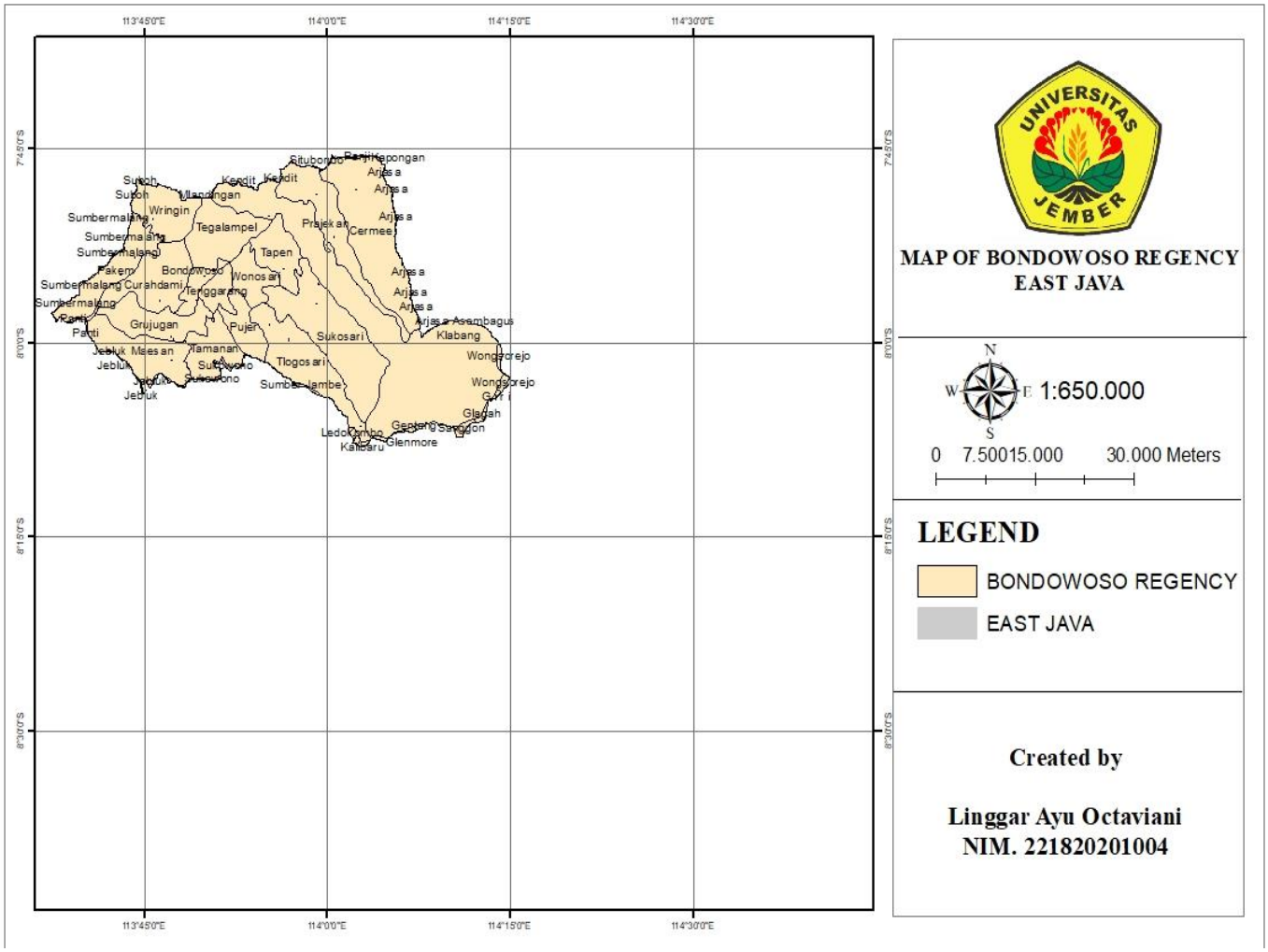

Figure 1. Map of the research area

Data Processing Method

In the implementation of this research, several stages were carried out as shown in Figure 2 below.

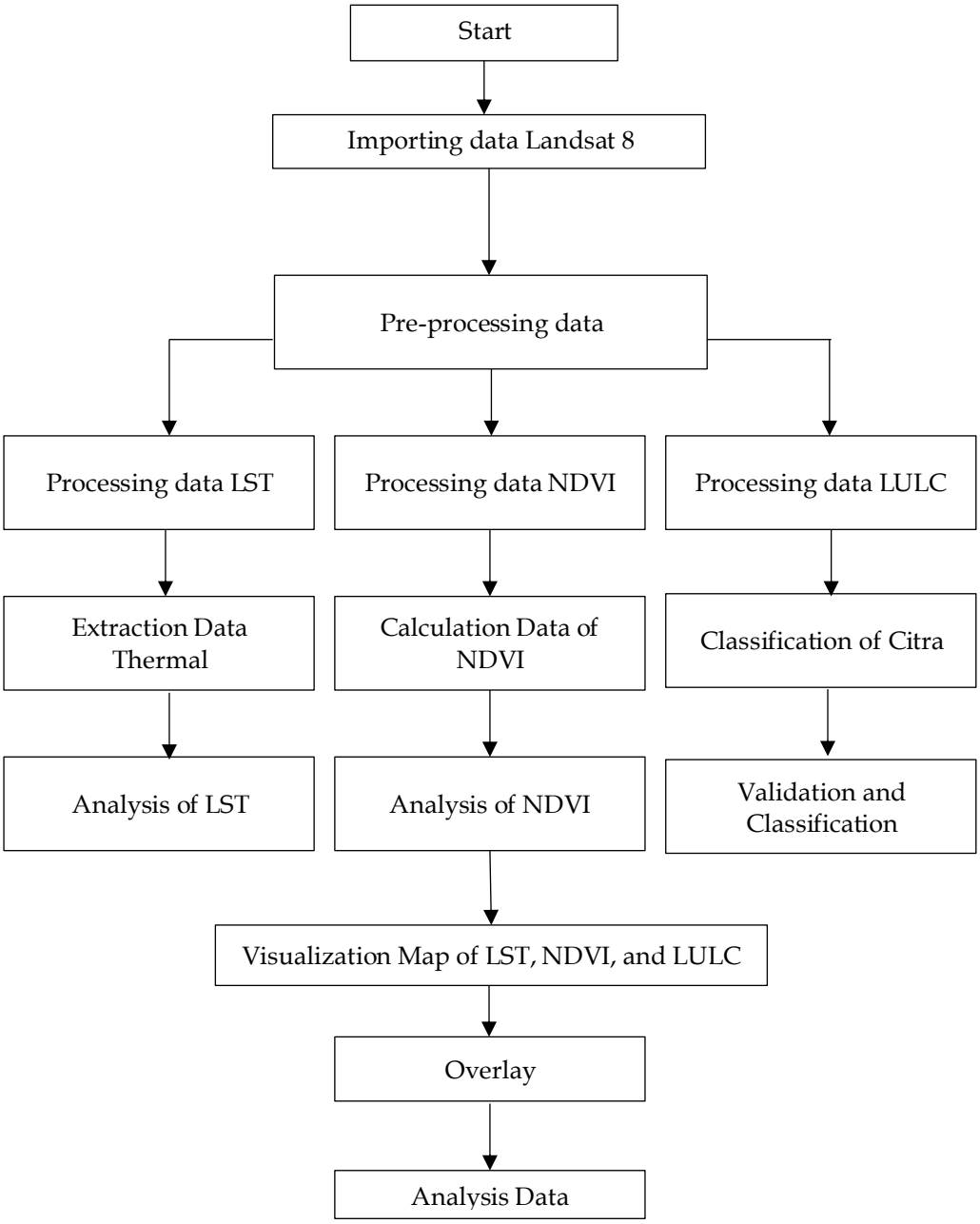

Figure 2. Research stage

Data Collection

Landsat imagery will be imported using Google Earth Engine (GEE) to obtain data on LST, NDVI, and LULC.

Data Processing

LST data will be processed using the Modified Brightness Temperature Index (MBTI) to identify areas with geothermal potential. In addition, LULC analysis will be conducted to understand land use change patterns. The latitude and longitude data generated by Landsat-8 will be used to determine the gravity distribution for Bondowoso Regency.

Result Visualization

The results of the analysis will be visualized in the form of maps to provide a better understanding of the surface manifestations of geothermal energy in Bondowoso Regency.

Interpretation and Analysis

The data obtained from the visualization will be interpreted and analyzed to identify patterns of relationships between LST, LULC, and geothermal manifestations in the area. NDVI values range from -1 to 1, where values close to 1 indicate denser vegetation, and values approaching -1 indicate sparse vegetation (Putri & Harianja, 2021). The NDVI value can be expressed by the following equation:

$$\text{NDVI} = \frac{\text{Band5 (NIR)} - \text{Band4 (Red)}}{\text{Band5 (NIR)} + \text{Band4 (Red)}} \quad (1)$$

The NDVI value is then used to calculate the vegetation fraction or vegetation proportion using the following equation:

$$\text{PV} = \left[\frac{\text{NDVI} - \text{NDVI}_{\text{min}}}{\text{NDVI}_{\text{maks}} + \text{NDVI}_{\text{min}}}\right]^2 \quad (2)$$

According to the classification based on the regulations of the Departemen Kehutanan (2012), the vegetation index obtained from the NDVI calculation can be divided into five categories: non-vegetated land, very low vegetation, low vegetation, moderate vegetation, and high vegetation, as listed in Table 1.

Tabel 1. Class of vegetation index

Class	Value of NDVI	Density level of NDVI
1	-1 ≤ NDVI ≤ -0.03	Non vegetated land
2	-0.03 ≤ NDVI ≤ 0.15	Very Low Greenness
3	0.15 ≤ NDVI ≤ 0.25	Low Greenness
4	0.26 ≤ NDVI ≤ 0.35	Moderate Greenness
5	0.36 ≤ NDVI ≤ 1	High Greenness

(Source: Departemen Kehutanan, 2012)

The LST value or land surface temperature distribution is obtained from Landsat-8 imagery. The data used is Band 10, which has a wavelength range of 10.30–11.30 micrometers with a resolution of 100 m (Permana et al., 2021). The LST value can be calculated using the following equation.

$$\text{LST} = \frac{\text{TIR}_1}{1 + \frac{(\alpha(\text{TIR}_{1)})}{\lambda}} - 273.15 \quad (3)$$

The analysis of LST, NDVI, and LULC data to understand the environment and geothermal potential is conducted using GEE and ArcGIS. The process includes data collection, processing with JavaScript code to input and calculate variables such as LST and NDVI, as well as temporal and spatial analysis to observe trends and distributions in the studied area. The results of the analysis are visualized in maps generated from GEE, and the data can be downloaded from Google Drive for further use in determining areas with potential geothermal activity using ArcGIS software.

Result and Discussion

The Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), and Land Use and Land Cover (LULC) are some of the parameters that are very useful in identifying the presence of geothermal manifestations in an area (Zaky et al., 2023). The map of NDVI distribution in Bondowoso Regency is shown in Figure 3 below.

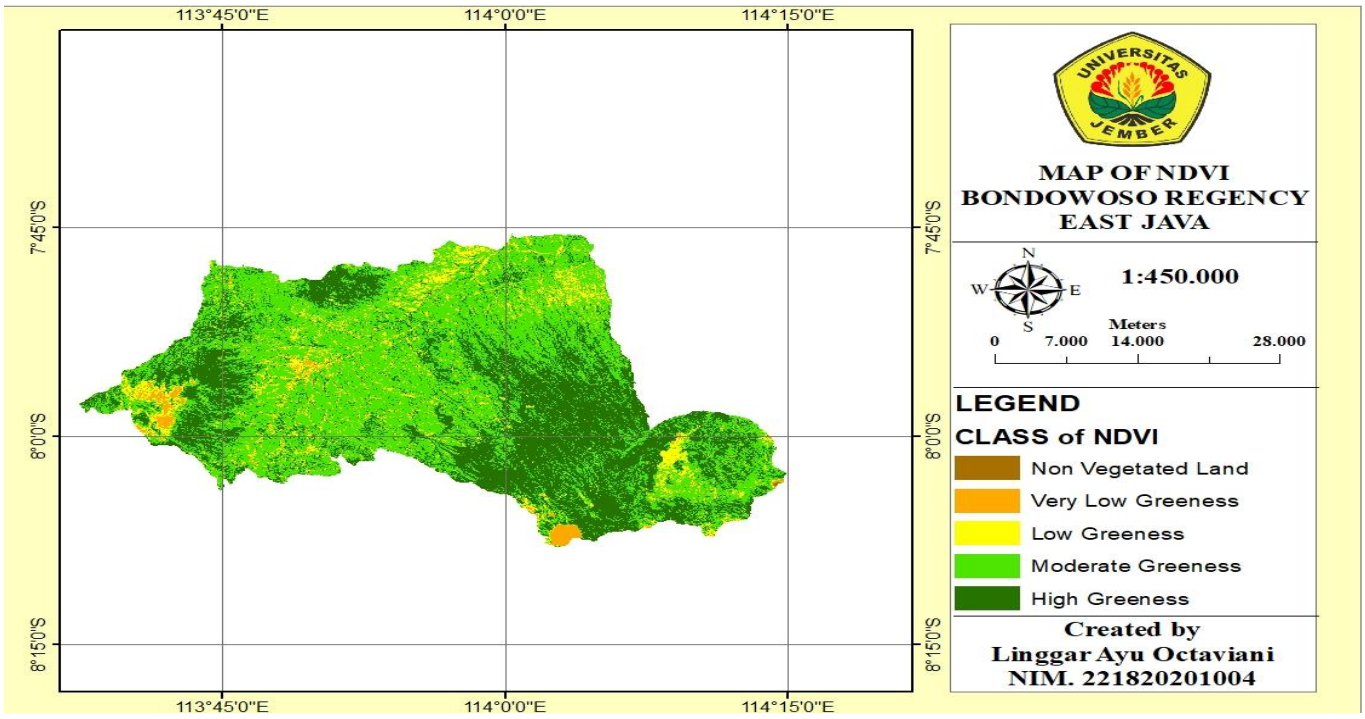

Figure 1. NDVI Map of Bondowoso Regency

The NDVI map for Bondowoso Regency, East Java Province, Indonesia, shows the variation in vegetation conditions in the area based on remote sensing data. NDVI is an index that measures the health and density of vegetation by utilizing the reflectance of red and near-infrared light from the Earth's surface. NDVI values range from -1 to 1, where positive values indicate the presence of vegetation, and higher values indicate healthier and denser vegetation. In this map, NDVI is classified into several categories: non-vegetated land, very low greenness, low greenness, moderate greenness, and high greenness.

Non-vegetated land, marked in brown, indicates areas devoid of vegetation, such as built-up areas, roads, or vacant land. Very low greenness, marked in orange, indicates areas with very little vegetation or severely stressed vegetation. Low greenness, marked in yellow, indicates areas with sparse vegetation, such as grasslands or sparse shrubs. Moderate greenness, marked in light green, indicates areas with reasonably healthy vegetation. Meanwhile, high greenness, marked in dark green, indicates areas with very healthy and dense vegetation, such as dense forests or lush plantations.

NDVI analysis is essential for understanding the vegetation conditions around geothermal manifestations. Areas with low NDVI or non-vegetated land may indicate surface temperature anomalies associated with geothermal activity, as geothermal heat can lead to soil conditions that are too hot to support healthy vegetation (Sekertekin & Arslan, 2019). Therefore, NDVI data can be used to identify areas of geothermal manifestations by observing vegetation anomalies.

The use of LST (Land Surface Temperature) data alongside the NDVI map can help accurately identify areas of geothermal manifestations. Areas with high LST and low NDVI are likely to be geothermal manifestation areas. The map of LST distribution in Bondowoso Regency is shown in Figure 4 below.

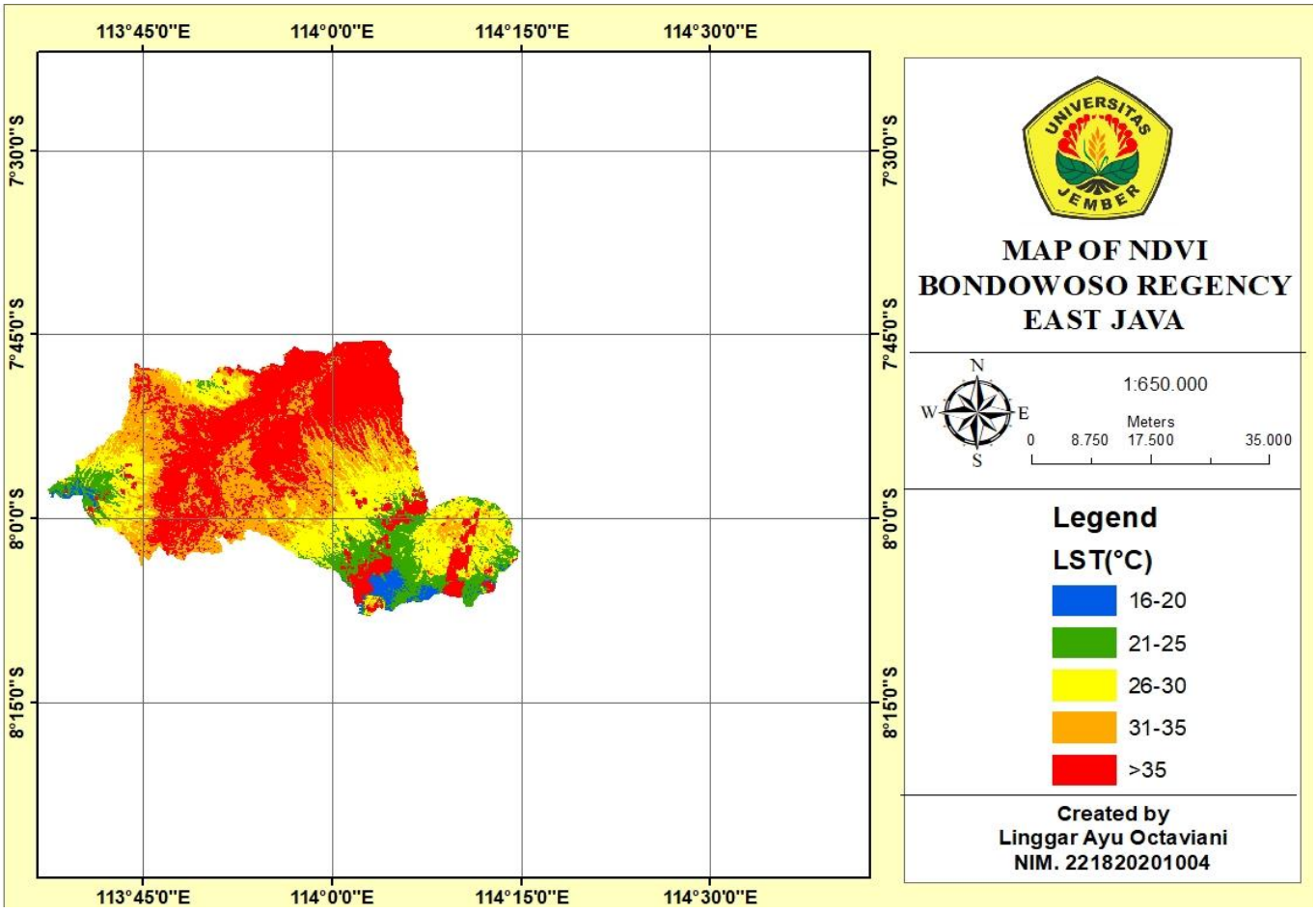

Figure 2. Map of LST Bondowoso Regency

Figure 4 shows that the distribution of LST in Bondowoso Regency varies significantly, with clearly identifiable temperature ranges. Areas with the lowest temperatures (16–20°C) are marked in blue and are

generally located in regions with high vegetation, such as forests or well-irrigated agricultural land. Moderate temperatures (21–25°C) are marked in green and typically cover open agricultural areas or rural regions. Warm areas (26–30°C) are marked in yellow and generally include open farmland as well as some areas that are beginning to urbanize. Hot areas (31–35°C) are marked in orange and likely include urbanized areas or degraded open land. Very hot temperatures (> 35°C) are marked in red, usually found in industrial zones, densely populated settlements, or areas affected by geothermal manifestations.

The heat distribution shows that most areas in Bondowoso Regency have very high temperatures (> 35°C), which are spread across the northeastern part of the regency. This indicates a potential for intensive human activity or geothermal manifestations. The areas with the lowest temperatures (16–25°C) are scattered in the southwest and central parts of the map, suggesting the presence of reasonably dense vegetation or good agricultural practices. The higher temperatures in the central to northeastern parts may indicate urbanization processes or infrastructure development that reduce vegetative areas and increase surface temperatures.

The use of LST (Land Surface Temperature) data alongside the NDVI (Normalized Difference Vegetation Index) map can provide deep insights into the environmental and vegetation conditions in a research area. When analyzing the potential for geothermal manifestations, the LST map can show variations in land surface temperatures that may be related to geothermal activity (Romaguera et al., 2018). The NDVI map provides information about vegetation density that can help identify changes potentially caused by geothermal influence (González & Rodríguez-Gonzálvez, 2019). Meanwhile, the analysis of LULC (Land Use and Land Cover) data is crucial in this context as it gives an overview of land use and land cover types in Bondowoso Regency. The LULC distribution map in Bondowoso Regency is shown in Figure 5 below.

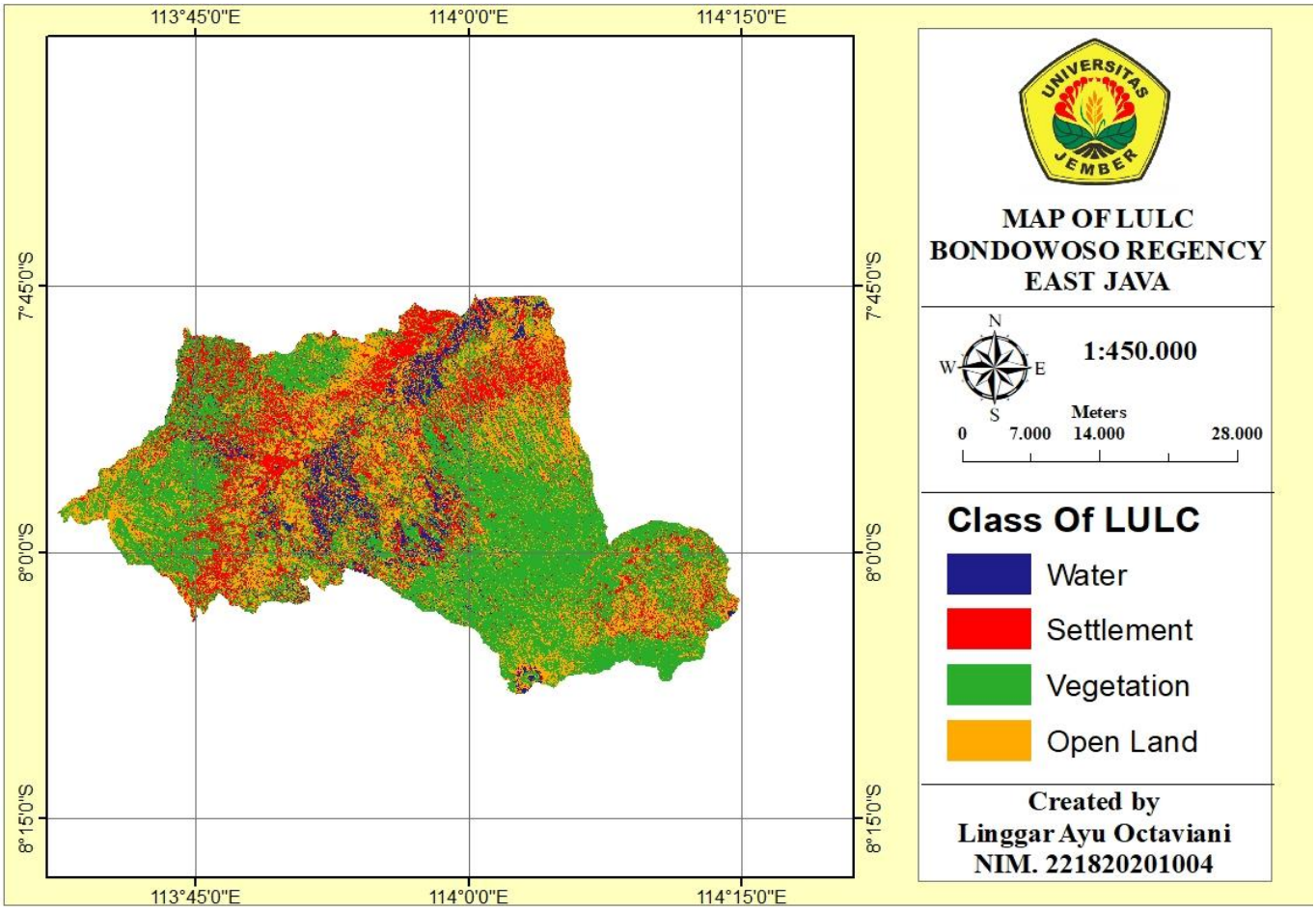

Figure 3. Map of LULC Bondowoso Regency

The LULC (Land Use and Land Cover) map for Bondowoso Regency, East Java Province, shows the variation in land use and cover in the area based on remote sensing data. The LULC categories in this map

include water bodies, settlements, vegetation, and open land, each marked with different colors. Water bodies are marked in blue and encompass aquatic areas such as rivers, lakes, and reservoirs. Settlements, marked in red, include residential areas and related infrastructure. Vegetation, marked in green, covers areas with significant vegetation cover such as forests and plantations. Open land, marked in orange, includes areas devoid of vegetation or water, such as vacant land and barren soil.

Based on this data description, the integration of NDVI, LST, and LULC in analyzing geothermal manifestations in Bondowoso Regency, East Java Province, allows for more accurate identification of geothermal manifestation areas. NDVI measures the health and density of vegetation, where low values may indicate vegetative stress due to geothermal activity (Mandal et al., 2022). LST provides information about land surface temperatures, with high values potentially indicating geothermal activity (Alqahtani et al., 2023). LULC data shows variations in land use and cover, such as water bodies, settlements, vegetation, and open land (Naikoo et al., 2020). This combination of data suggests that areas with high LST and low NDVI, particularly in settlement or open land areas, are likely strong indicators of geothermal activity (García et al., 2023). This approach enables more effective mapping and analysis in identifying and managing geothermal resource potential in the region. The distribution of high temperatures (> 35°C) in the northeastern part of Bondowoso Regency, identified through LST data, along with low NDVI values and appropriate land use types from LULC data, indicates potential geothermal manifestations in that area.

Conclusion

This study concludes that the analysis of remote sensing data, including LST, NDVI, and LULC, is effective in identifying and understanding geothermal manifestations in Bondowoso Regency. Areas with high surface temperatures (high LST) and stressed or non-vegetated conditions (low NDVI), particularly in settlement or open land areas (LULC), indicate a strong likelihood of geothermal activity. For example, the high temperatures (> 35°C) in the northeastern part of Bondowoso Regency, along with low NDVI values and land use data, suggest potential geothermal manifestations. This integrated approach allows for more accurate and effective mapping for managing geothermal resources in the region.

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Author Contributions
Conceptualization, L.A.O. and B.E.C.; methodology, software, formal analysis, investigation, resources, data curation, writing—original draft preparation, visualization, L.A.O.; validation, writing—review and editing, L.A.O., B.E.C., and A.S.; supervision, project administration, B.E.C. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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