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Preliminary assessment of the Pentadio geothermal prospect, Gorontalo, Indonesia

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ABSTRACT

The Pentadio Geothermal Prospect is situated in Telaga Biru, Gorontalo, Indonesia, and falls into the category of a low to medium geothermal resource associated with the Gorontalo graben on the northern arm of Sulawesi Island. Identifying geothermal potential in such low to medium resource areas poses challenges due to the absence of vigorous thermal features commonly found in high-temperature fields. Therefore, this study aims to identify geothermal potential on this type of field by integrating remote sensing analyses. Remote sensing techniques, specifically land surface temperature (LST) overlayed with lineament density analysis are considered powerful tools for the preliminary assessment of this geothermal resource potential. These features exhibit a strong correlation with indicating geothermal presence in such areas. The study will utilize open-source data, such as Moderate Resolution Imaging Spectroradiometer (MODIS) derived from Google Earth Engine (GEE), to identify Land Surface Temperature anomalies, while lineament density will be sourced from DEMNAS imagery. It is expected that anomalies recorded through remote sensing analyses will exhibit a positive correlation with field observations, such as the presence of active thermal manifestations.

1. INTRODUCTION

The Gorontalo section of the northern arm of Sulawesi Island, traversed by a longitudinal median depression, is deemed volcanically extinct (van Bemelen, 1949). Despite this, it hosts one geothermal prospect in Gorontalo, known as Pentadio. According to the Directorate of New and Renewable Energy (EBTKE), Pentadio falls within the category of a low to medium geothermal resource, controlled by the fault system (EBTKE, 2017). The prospect currently holds a speculative resource of 25 MWe and is included in the Preliminary Survey and Exploration Assignment Geothermal Area (WPSPE) by the Ministry of Energy and Mineral Resources, Indonesia (MEMR). While some studies suggest abundant prospects for low to medium geothermal systems in Indonesia, including Pentadio, none of these prospects have been developed due to inadequate data and information (Wibowo et al., 2021; Putriyana et al., 2022).

To date, low to medium geothermal resources in Indonesia are still considered less attractive, possibly due to characteristics that are not well understood. For instance, active thermal features such as warm and/or hot springs may not be as appealing as those in high-temperature geothermal fields with fumarolic/solfataric steam discharge, boiling hot pools, etc. Moreover, some fields may lack surface thermal features, also known as blind/hidden geothermal systems. Conventional exploration and extraction concepts applied in high-temperature systems may not be fully suitable for these conditions, leading to very high resource risk and impacting economic value. Understanding the exploration strategy for this type of field is critical to accelerating its development in Indonesia.

Along with technological advancements, various techniques can be utilized to optimize the identification of geothermal prospects, particularly for low to medium resources. One such method is identifying structural indications and surface thermal anomalies using remote sensing imagery. This paper is part of our study aiming to analyze the utilization of advanced remote sensing techniques to identify features correlated with indicating geothermal presence in a geothermal field. Pentadio prospect is chosen due to its low to medium resource characteristic and non-volcanic setting, shedding light on whether similar techniques can be applied to other comparable fields in Indonesia.

2. METHODS

The research utilized a digital elevation model (DEM) sourced from DEMNAS with an 8-meter spatial resolution. This DEM was used to create hillshade representations at angles of 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315° with an altitude of 45°. The diverse range of illumination angles ensures comprehensive visibility of all slopes from distinct perspectives. The data used to generate land surface temperature (LST) was derived from the Google Earth Engine (GEE) platform, utilizing the Moderate Resolution Imaging Spectroradiometer (MODIS) Terra Land Surface Temperature product. This provides LST data around the world with a spatial resolution of 1 km.

Nighttime data was preferred, considering it may be more representative due to being less influenced by solar heating differences, which can swamp out subtle temperature variations caused by geothermal activities. The thermal anomalies detected were then correlated with the digital extraction lineament and the location of thermal manifestations to determine if there is any spatial relationship between these features. The Google Earth Engine view is displayed in Figure 1, while the workflow to generate land surface temperature is demonstrated in Figure 2.

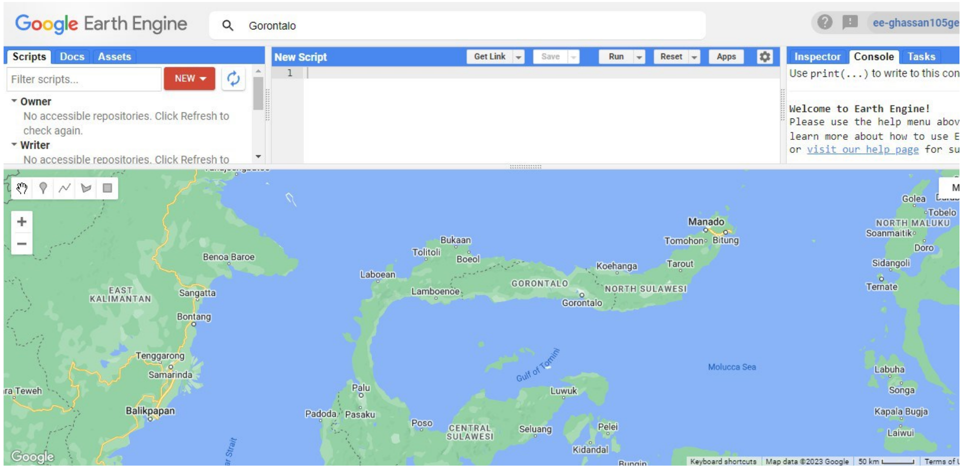

Figure 1 The Google Earth Engine view.

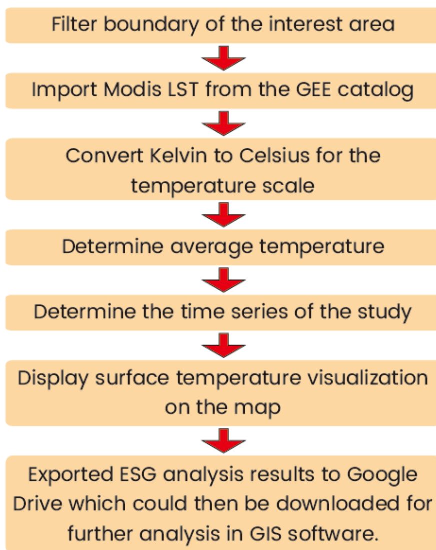

Figure 2 The stages of land surface temperature data processing for this study utilizing Google Earth Engine (GEE).

3. DISCUSSION

3.1 Physiography

The north arm of Sulawesi is part of the Sangihe volcanic arc, formed by the subduction of the Molucca Sea plate to the west, according to Hamilton (1979). In contrast, the Halmahera volcanic arc resulted from the subduction of the Molucca Sea plate to the east. As outlined by van Bemmelen (1949), the north arm of Sulawesi exhibits a sinuous appearance, distinguishable into three parts: the highly volcanic eastern end with a NE-SW trend (Minahasa area); the central part, characterized by the rotation of the main trend from a NE-SW to E-W direction, forming a longitudinal depression and being volcanically extinct (Gorontalo section); and the N-S trending part.

The North Sulawesi Trench ends at the east where the northeast tip of the Nort Arm of Sulawesi curves from an easterly trend to a northerly. Some volcanoes that become extinct in Quaternary time continue westward some distance from this bend, while the still active volcanoes on Sulawesi are now confined to the northeast tip of the North Arm (Hamilton, 1979). Pentadio is situated within the central arm of the Gorontalo physiographic section. This section is longitudinal median depression which stretches between the mountain ranges on the North coast on the E-W direction called Limboto Zone where the volcanism is entirely extinct (van Bemmelen, 1949). This depression zone is the prominent feature which can be seen around Pentadio prospect. EBTKE (2017) expected that this depression structure is controlling the geothermal system in Pentadio.

3.2 Stratigraphy

According to the geological map presented by EBTKE (2017), the stratigraphy in Pentadio can be generally grouped into Old Volcanic Products, Intrusion Rocks, Sedimentary Rocks, Young Volcanic Products, and Surficial Deposits based on their relative age and rock type. The geological map of Pentadio is presented on the Figure 3.

a) Old Volcanic Products consist of basaltic lavas which is locally distributed on the southwestern coast of the interest area, pyroclastic rocks at the eastern part of the prospect, and andesitic lavas which cover most of the field in the northern and southern part.
b) Intrusion Rocks which partly can be seen in the NW, NE, and S of the field. There is no information related to the composition of the intrusion rocks.
c) Sedimentary Rocks consist of sand-silt stones which is partly distributed on the NW and S part of the Limboto Lake. Limestones is dominantly covering the western part and partly exposed on the south coast.
d) Young Volcanic Products resulted from two young volcanoes namely Lampotoo and Pilomba which can be found at the eastern and western edges on the interest area, respectively.
e) Surficial Deposit which is expected derived from the lake deposits and distributed along the E-W direction around the Limboto Lake.

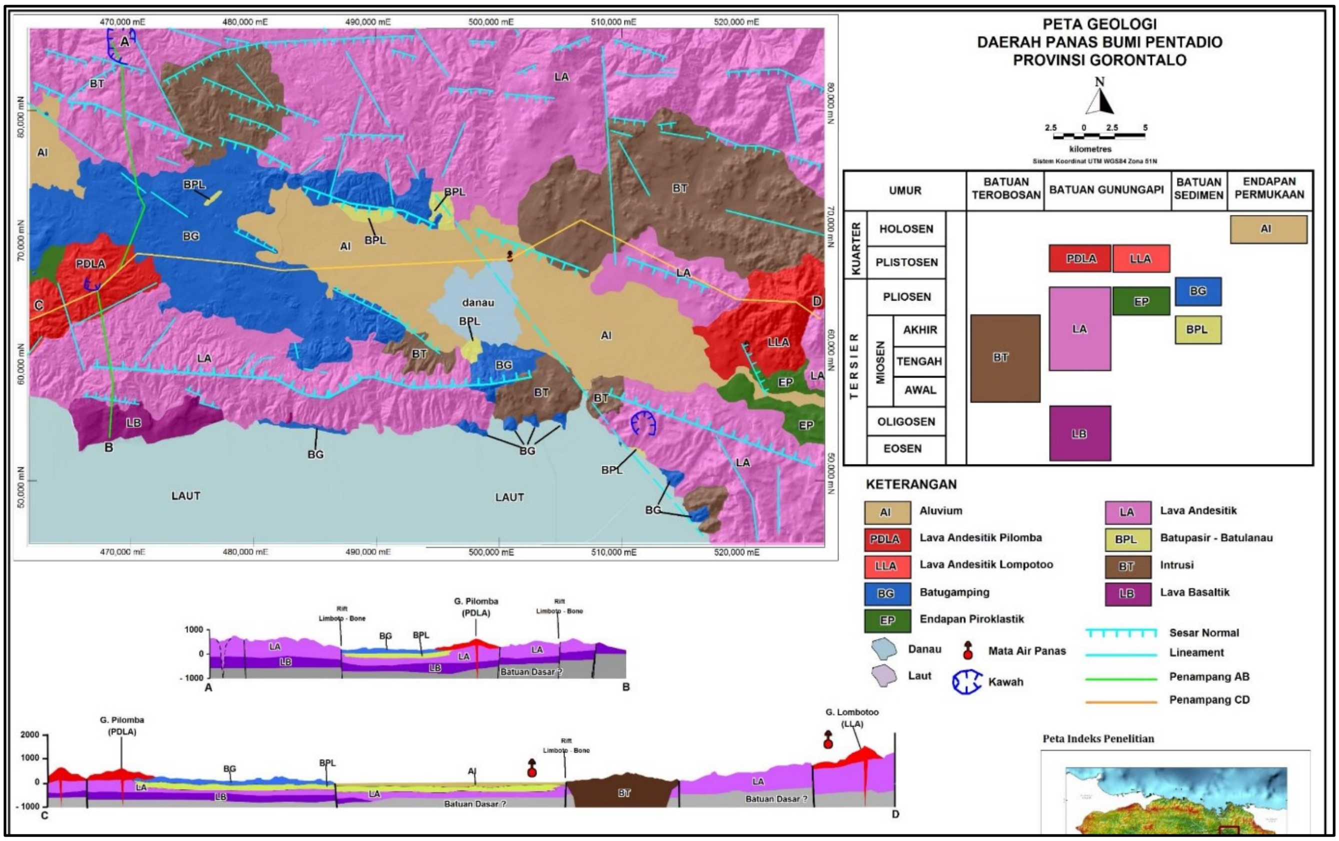

Figure 3 Geological map of Pentadio geothermal prospect (EBTKE, 2017).

3.3 Geological structures

The geological structures interpreted from DEMNAS revealed that the main structures in Pentadio trend in an east-west direction. Two significant dip-slip faults bound the depression zone, interpreted by van Bemmelen (1947) as the Limboto Zone. The thermal manifestations in the Pentadio prospect are situated within this depression zone. DEM imagery was further processed to automatically generate surface lineaments based on the scanned surface conditions by the software, as shown in the digital elevation map of the Pentadio area in Figure 4.

Lineament density, or fault and fracture density (FFD), is defined as the total length of lineament per unit area (Soengkono, 1999). The lineament density in the research area was divided into a 1 km grid system. The total length of lineaments inside each grid (in km) was measured, and the results were used to compute a representative value of FFD (in km/km²) at the center of the grid (Soengkono, 2010), ranging from 0 to 0.809 km/km². It is worth noting that while ideally, the extracted lineaments in valleys and ridges should be differentiated manually to obtain a more representative alignment associated with geological structures, this filtering was not conducted in this study.

The results of the analysis indicate that the thermal feature is not precisely located adjacent to the fault, nor is it overlaid in areas of high FFD density. The location of the manifestation is also at a considerable distance from the lineaments. Furthermore, in comparison to the Te Kopia Field, where the geothermal reservoir is associated with FFD values ≥3 km/km² (Soengkono, 1999), the FFD value in Pentadio is significantly lower (maximum 0.809 km/km²). Therefore, the role of the structures in Pentadio as permeable pathways still needs further study. The digital extraction lineament and lineament density maps of Pentadio are presented in Figure 5 and Figure 6, respectively.

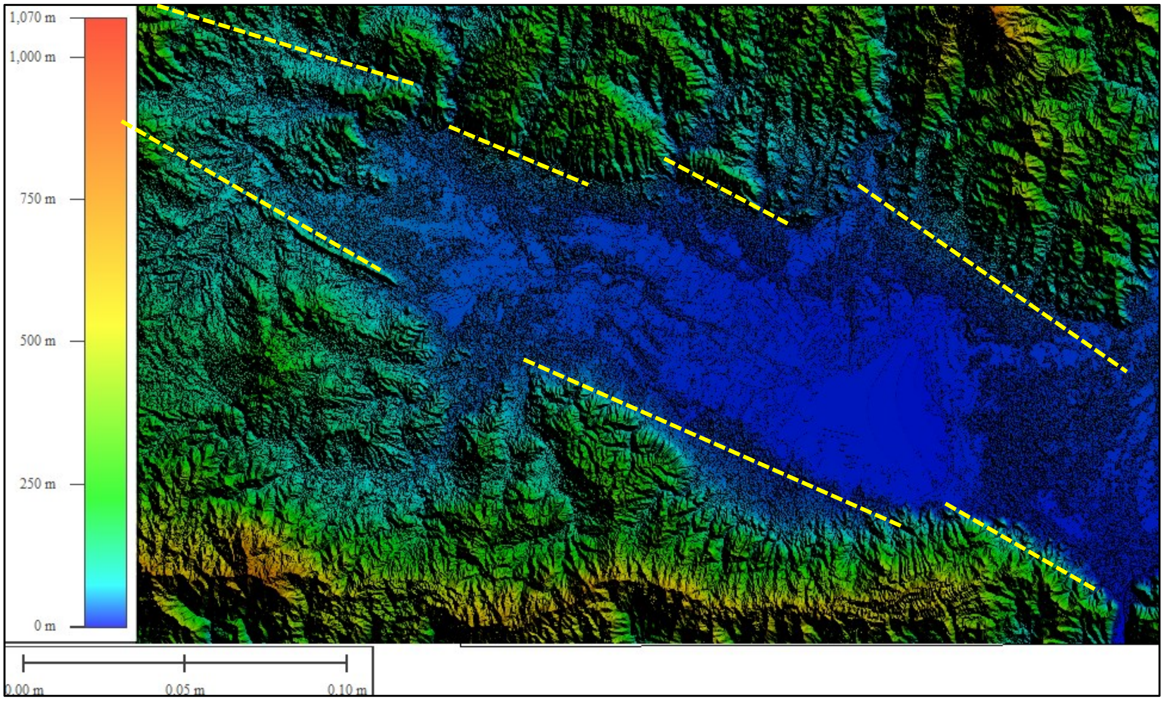

Figure 4 Digital elevation model which shows major WNW-ESW lineament at Pentadio.

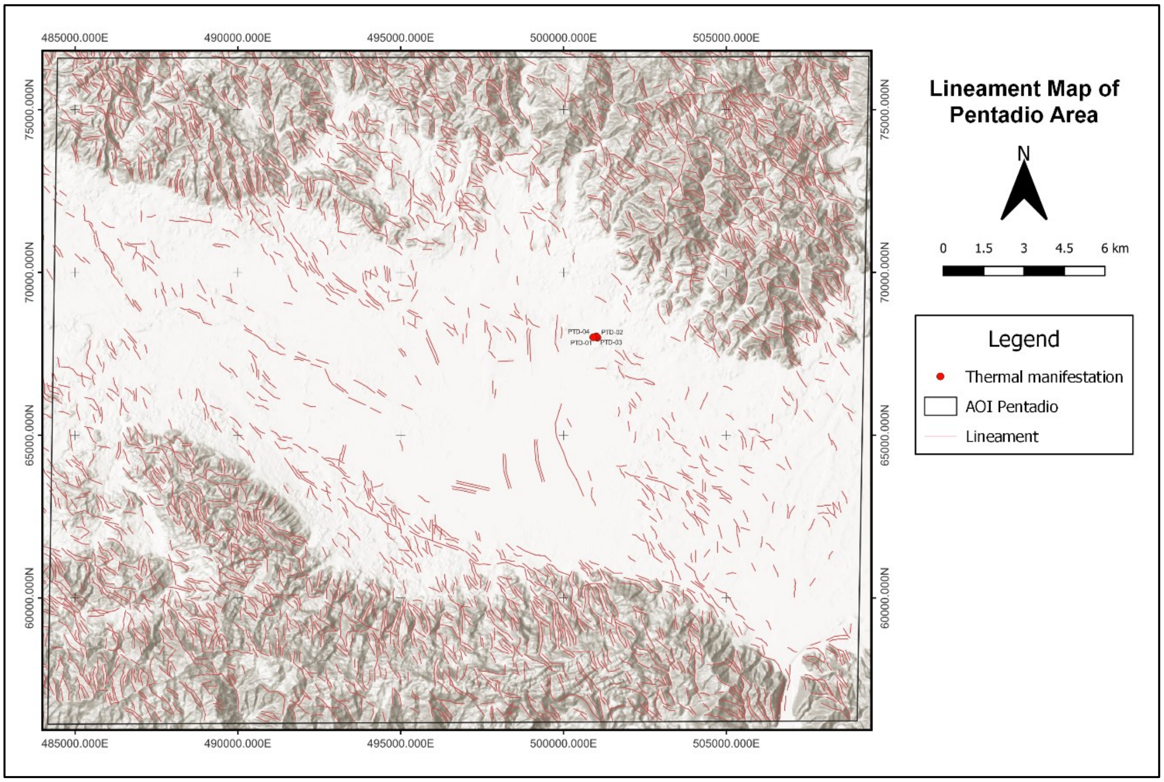

Figure 5 The digital extraction lineament map reveals a dominant WNW-ESW trending in Pentadio. Several lineaments with NE-SW orientation are also recorded in the hilly terrain on the northern and southern parts of the field.

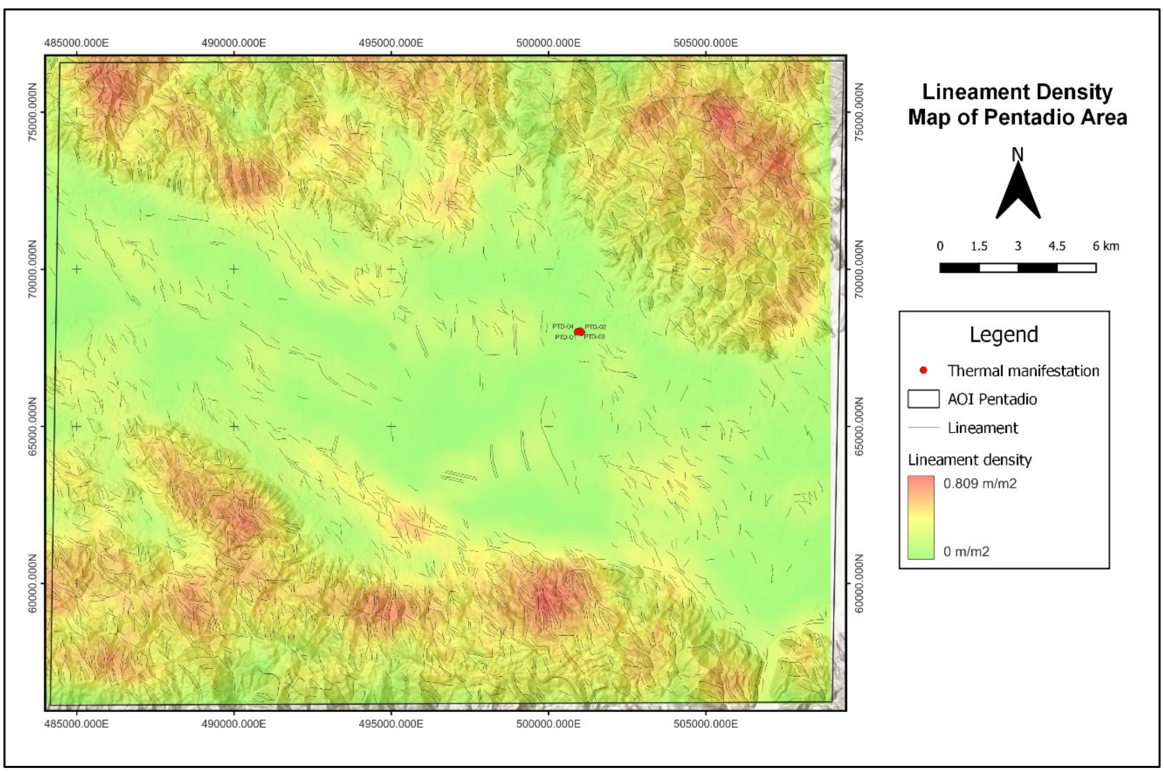

Figure 6 The lineament density maps display a range from 0 to 0.809 km/km². A high-density anomaly (indicated by the red color) is observed only at the northern and southern parts of the field and does not correlate with thermal discharge in the central part.

3.4 Thermal manifestation

Thermal manifestations in Pentadio are situated at about 9 to 15 mRL. These manifestations emerge on the alluvial plain and are located in a singular position at the northeast part of the Limboto Lake. They manifest as hot springs and hot pools with temperatures ≥70℃ (EBTKE, 2017). Further investigations into the physical characteristics of these thermal manifestations will be conducted during a future site visit by Geoenergis. This will include altered ground observation, sampling, and analysis to gain a better understanding of the thermal characteristics and evolution present in Pentadio.

3.5 Surface thermal anomaly

The thermal anomalies in the Pentadio area are the result of MODIS imagery processed using Google Earth Engine (GEE) platform. Both the data and software are open-source, making them very helpful for the initial reconnaissance of a geothermal prospect. The imagery data used is from nighttime recordings in 2016. Nighttime images are generally more representative for Land Surface Temperature (LST) analyses as they are less influenced by the effects of differential solar heating, which can mask subtle temperature differences due to geothermal activities. Additionally, nighttime images provide a contrast between anomalies and the background temperature (Meer, et al., 2014).

Based on the Land Surface Temperature map produced (Figure 7), the surface temperature in the Pentadio area ranges from approximately 21.64°C (green color) to a maximum of 24.59°C (red color). The high anomaly is widely distributed in the western part of the area of interest, where the Pentadio spring is only slightly located at the edge of the anomaly. Although the temperature of the thermal spring is considerably high (≥70°C), the resulting land surface temperature does not seem well-correlated with the thermal spring's existence and also does not indicate higher temperature conditions (maximum temperature 24.59°C).

The wide distribution of a high anomaly in the western part may represent a false anomaly, possibly caused by the presence of the large water body of Limboto Lake. Water bodies are considered to have higher heat capacity, causing them to cool down more slowly at night than solid rocks and dry soils in their surrounding areas. In most cases, estimating the thermal spring directly from the image temperature is challenging since the area around objects cools down more slowly compared to the trace of remote sensing imagery (Meer, et al., 2014).

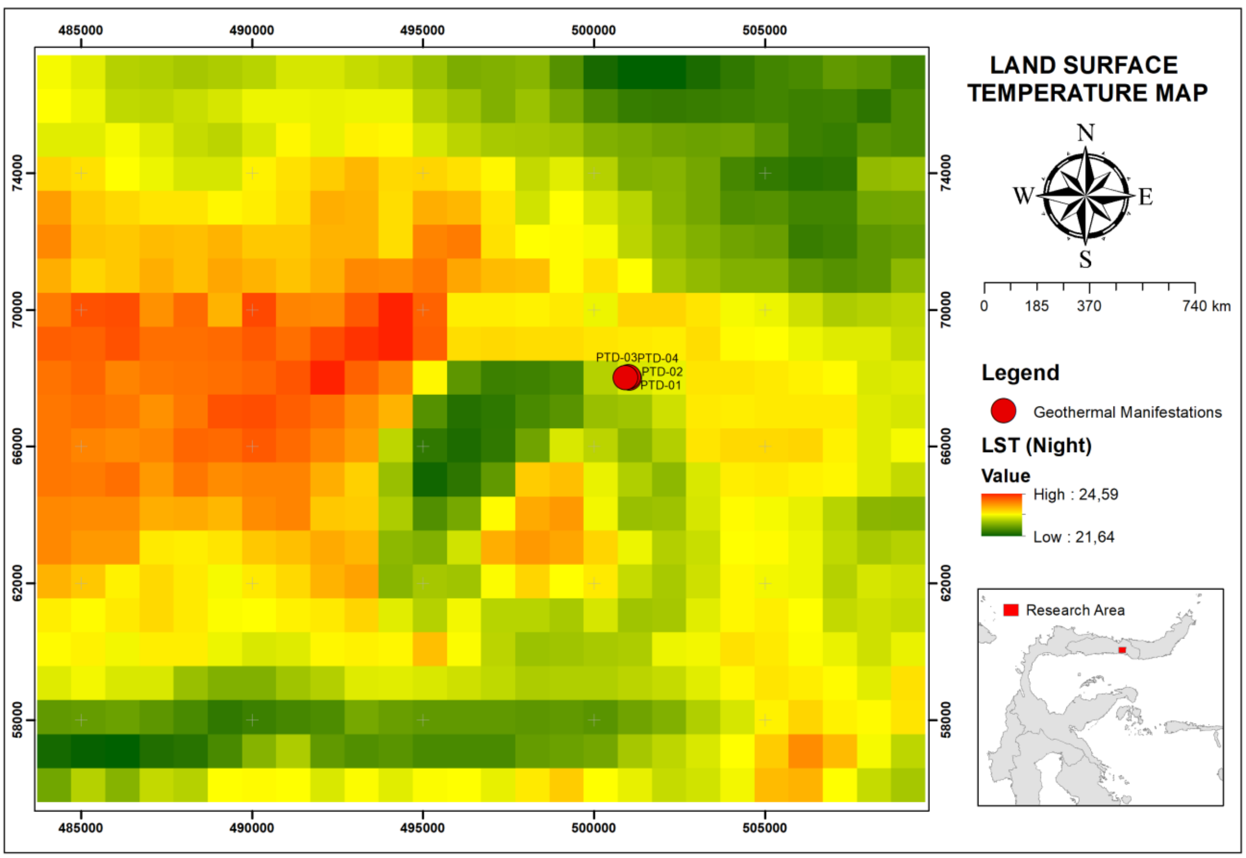

Figure 7 Land surface temperature anomaly map of the Pentadio field.

4. CONCLUDING REMARK

The land surface temperature map, lineament distribution, and thermal manifestations in Pentadio do not show any clear correlation among these features. While high lineament density is observed in the southern and northern parts of the Pentadio area, the FFD value is significantly low (maximum 0.809 km/km²), and there is no distinct association between lineament density and thermal features. The manifestations are only slightly located at the edge of the surface thermal anomaly, despite the presence of a relatively high-temperature spring. Ground checking will be conducted to confirm the anomalies resulting from remote sensing analyses, providing a better understanding of the geological and geothermal signatures at the Pentadio field.

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