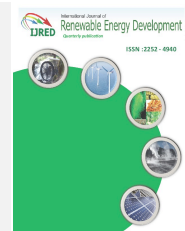




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Research Article

# Remote Sensing Satellite Imagery and In-Situ Data for Identifying Geothermal Potential Sites: Jaboi, Indonesia

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**ABSTRACT.** Remote sensing makes it possible to map potential geothermal site for a large area effectively using thermal infrared. The purpose of the present research is to overlay ground temperature, resistivity and satellite retrieved temperature in identifying geothermal potential site in Jaboi, Sabang-Indonesia. The data of acquisition of the DEM imagery was January 3rd, 2009 and the Landsat 8 imagery is July 18th, 2017. The satellite data were applied to extract the land surface temperature and land classification across. Two supporting data in situ were used to validate the results from remote sensing. First dataset was ground temperature measurements with total 114 points and second dataset was vertical electrical sounding (VES) with total of 51 points. Satellite, VES and ground temperature data were processed and analysed using the Envi 5.3, PCI Geomatica 2016 and ArcMap 10.4. The results from each data were integrated to produce a map shows geothermal potential. Its integration produced four areas which were considered to have high geothermal potential. However, these areas vary in term of the clustering of the features of interest, for example lineament and drainage density of the area, high temperature in the surface area, fault existence and low resistivity subsurface. All the features must take into consideration to rank potential area which has higher potential. Finally, a map of geothermal potential across were successfully created as an insight for future reference. ©2020. CBIOR-IJRED. All rights reserved

**Keywords:** Geothermal; energy; temperature; satellite data; electricity

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## 1. Introduction

Heat source that is trapped under the Earth's crust well is known as geothermal. Volcanoes, fumaroles, hot springs and other geological thermal phenomenon on the surface of the earth are the manifestation of the geothermal hotspots site (low or high temperature) beneath the surface (Bayer *et al.* 2019; Hochstein and Sudarman 1993; Qin *et al.* 2011; Taqiuddin *et al.* 2016; Risdianto and Kusnadi 2010). Geothermal system consists of reservoirs (hot or cold temperature). Heat sources itself, any fluids which carry and transfer the heat, and recharge areas through faults (Taqiuddin *et al.* 2016). The heat source under the Earth's crust is caused by tectonic plate (active) margins which represent major zones of magmatic matter that is radioactivity and cooling (Uysal 2009). The hot reservoir in the geothermal system is the bulk of rocks from which heat can be extracted. This contains various gases, vapour and fluids in relatively high temperature. The reservoir is surrounded by rocks (cold) through which water flows from the outside into the hot reservoir. The reservoir area which water flows or other fluids into the reservoir is called the recharge area. The hot fluids in the reservoir move due to

buoyancy forces through a discharge area by some distance. Recognition of prospective geothermal site in the aseismic geologic setting using conventional techniques is much challenging and costly. Therefore, the remote sensing technology applicability to detect spatial patterns such as thermal anomaly offers a cheap and useful technique (Calvin and Pace 2016). Remote sensing technology began to be developed and used after the World War II where it is limited to military use only. Over time, remote sensing began to be more developed and used widely for civil use. Remote sensing has been used in many ways including agriculture, forestry, geology, hydrology, mapping, ocean and coastal and exploration. Technological advancement in remote sensing (satellite sensor: optical or thermal) nowadays makes it feasible to map potential geothermal heat anomalies at a large scale effectively by utilizing various features aboard the satellites that can assist in determining geothermal activity such as land surface temperature, land feature classification, lineaments mapping and drainage. (Hewson *et al.* 2020; Hariyanto and Robawa 2016; Srivastava *et al.* 2010; Urai *et al.* 2002; Bouazouli *et al.* 2019; Abubakar *et al.* 2019). The relatively

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save time consumption, cheap and high observation accuracy makes it useful as the first phase in exploration to supply data and information for farther studies. Also, topography condition and regulation of an area such as restriction to conduct any survey on land owned by residents make it even more difficult to conduct a survey. Remote sensing technology data such as ASTER, MODIS/ASTER or MASTER, TIMS, and Landsat TM,

Landsat 7 ETM+ and Landsat 8, have thermal infrared (TIR) bands, and have been used for geothermal exploration and monitoring (Hochstein and Dickinson 1970; Hodder 1970, Dean *et al.* 1982; Eneva *et al.* 2006; Heasler *et al.* 2009; Qin *et al.* 2011; Prakash 2012; Haselwimmer *et al.* 2013; Fitts 2013; Mia *et al.* 2014; Tian *et al.* 2015; Nishar *et al.* 2016; Bromley *et al.* 2011 Coolbaugh *et al.* 2007;).

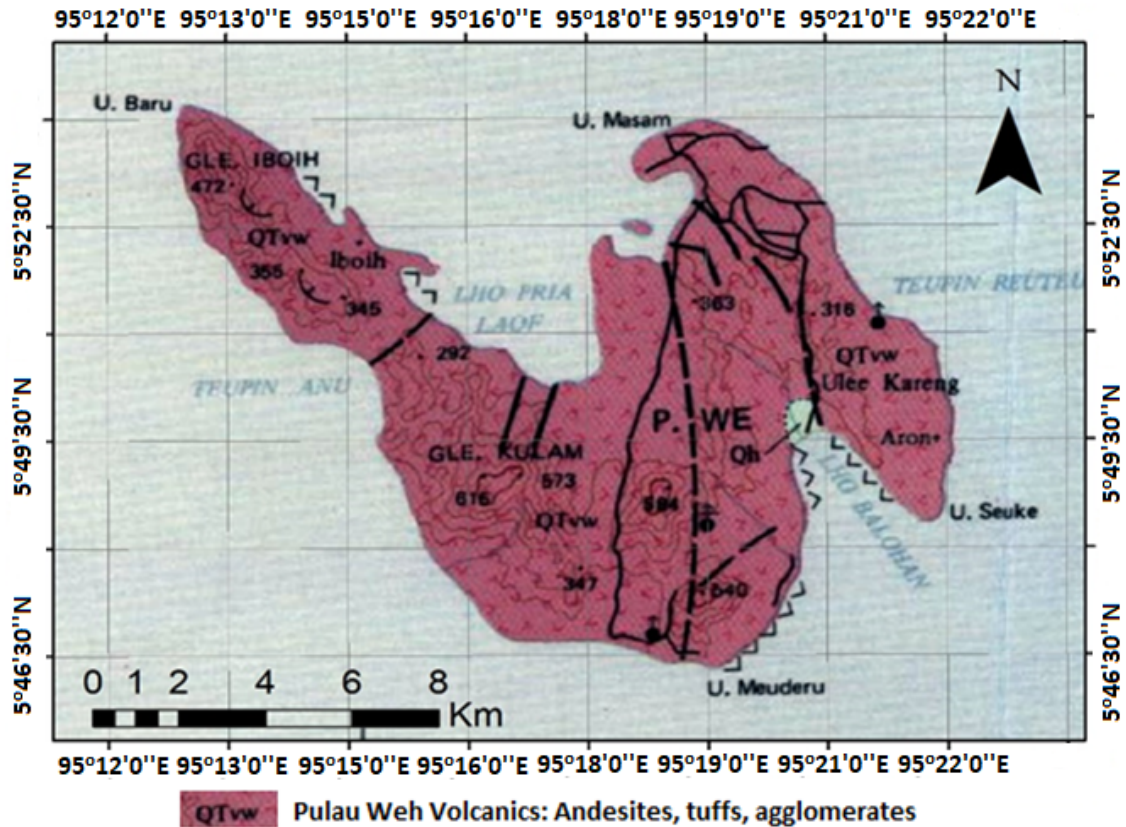


Fig. 1 The geological of the study area (modify from Geological Research and Development Centre of Indonesia, 1981).

Landsat 8 has the capability to give reliable information on surface temperature using infrared sensors (Seward *et al.* 2018; Sekertekin and Arslan 2019). It can retrieve not only land surface temperatures but also to obtain vegetation density which is very useful in the determination of geothermal potential site (Qin *et al.* 2011). Even though satellite imageries are effective, it is fundamental that ground temperature measurements are carried out to validate the data results from remote sensing. Geophysical methods such as magnetic, gravity, geo-electric survey can be performed as supportive data to validate the data measurement retrieve from remote sensing. As exploration activity dealing with uncertainty, integration of various methods must be done to get reliable results. The data from satellite imageries then will be compared with ground surveys to validate the results from remote sensing. With remote sensing method, the survey can be done by focusing only on areas that are considered to have geothermal potential. With that, the survey can be done with an efficient time and less human labor.

The study area in the present paper is in Weh Island, which located on the western tip of the Indonesian territory

of Sumatera Island. Investigations have been conducted on the surface manifestations of geothermal activity (Budak 2004) and boundary manifestations in the present geothermal area (Prihadi *et al.* 2010). Geothermal research at Jaboi, Sabang began in 1972 with a survey (Akbar *et al.* 1972) and investigation of geothermal surface manifestations (Akbar and Dendi 1983). An intensive collection of geological, geochemical and geophysical studies and datasets have been developed by many authors, such as Widodo and Suhanto (2005). Moreover, Akbar (2009) formulated a geothermal conceptual model, whereas Widodo and Suhanto developed a tentative model for this region. The Jaboi geothermal area is characterized by the existence of three geothermal manifestation groups on the surface; they are geothermal Iboih, Lho Pria Laot, and Jaboi. The latest geothermal area is administratively mostly included in the Sukajaya subdistrict and a small part in Sukakarya Subdistrict, Sabang City, Aceh Province. The location can be reached by speed boat with 1.5 hours travel time from Uleelee port, Aceh to Balohan port on Weh Island, which then proceeds by road 2 km to the west from Balohan port. The surface manifestation of its activity can

be indicated by hot springs, fumaroles, hot mud and hydrothermal altered area (Isa *et al.* 2013). Many researches have been conducted to study the geothermal activity of the present area (Dirasutisna and Hasan 2005, Dwipa *et al.* 2006, Munandar *et al.* 2007).

Figure 1 shows the geology of the study area (geological map area). The area took place in Mount Jaboi in Weh Island. The mountain is located at about 10 km south of Sabang city, Indonesia, with coordinate of 5°48'28.93"N and 95°19'44.88"E. Based on the observation from the available geological map, multiple hills can be seen around the study area which may have formed from tectonic activities of the Sumatera fault system. The map suggested that the island is a volcanic island that composed of andesites, tuffs and agglomerates (Cesarian *et al.* 2018). Another finding on the geological condition of this island explained that stratigraphically the island consists of four main groups of rock units. The oldest rock is Tertiary sedimentary rocks followed by Tertiary-Quaternary volcanic rocks of Weh, Young/Quaternary volcanic rocks and limestone (Dirasutisna and Hasan 2005). This study aimed to identify geothermal potential sites at a large scale effectively using

satellite data retrieve from Landsat-8 and validate the retrieval results data with vertical electrical sounding, supporting data of geological map and finally ground temperature measurements.

**2. Materials and Methods**

A Landsat 8 imagery of the study are was downloaded from Earth Explorer - United States Geological Survey (USGS) with Path Type WRS 131 and Row 056 (Fig. 2(a)). The acquisition date is on July 18th, 2017. The imagery projection is UTM WGS84 Zone 46. The spatial resolution is 30 m for bands 1 - 7 and 9, 15 m for 8 (panchromatic) and 100 m for 10 and 11 (thermal). This satellite data was applied to extract the land surface temperature and land classification across the study area. Another satellite data used in this study was the ALOS Phased Array type L-band Synthetic Aperture Radar (ALOS PALSAR DEM) data which was downloaded from the Alaska Satellite Facility website (Fig. 2(b)).

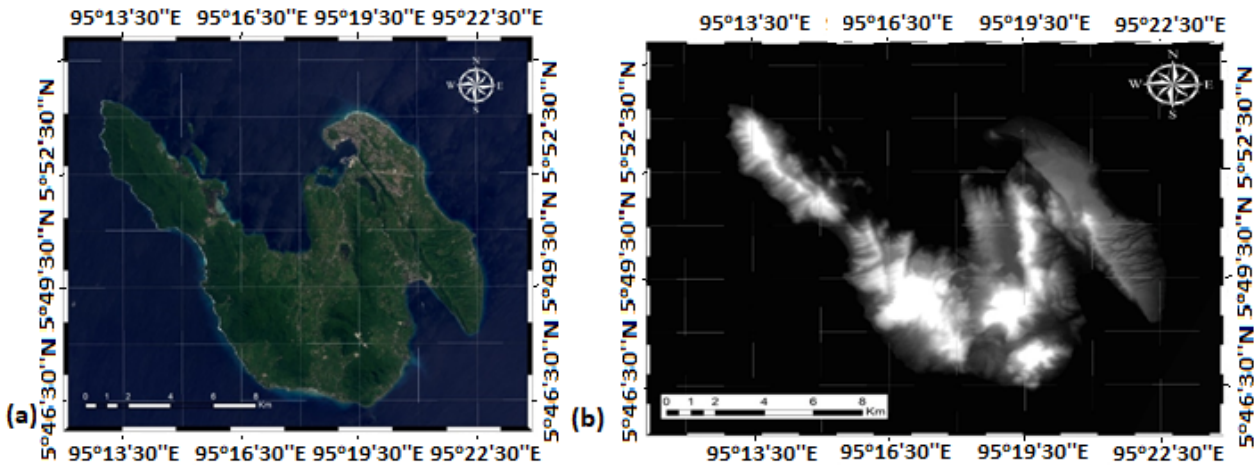


Fig. 2 (a) True color image from Landsat 8 satellite (b) ALOS PALSAR Digital Elevation Map (PALSAR DEM) of the study area

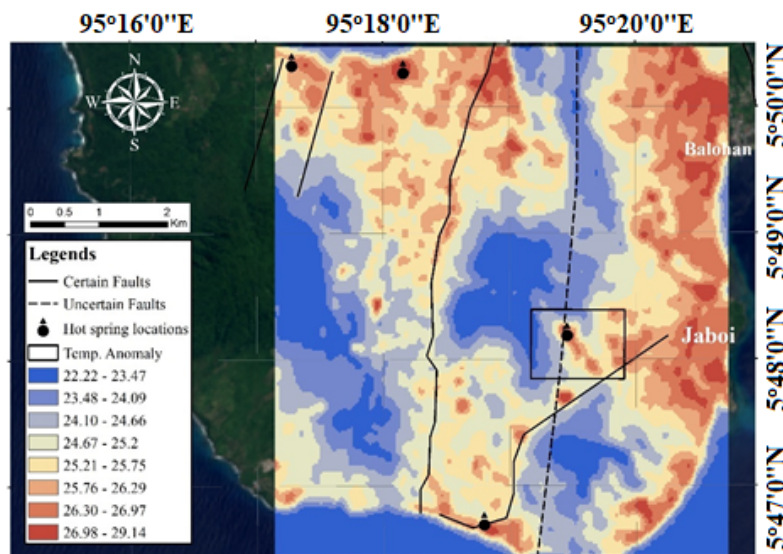


Fig. 3 (a) Land surface temperature of the present study varies from 22 to 29°C



The acquisition date of the DEM imagery was January 3rd, 2009 and it has the projection of UTM WGS84 Zone 46. The imagery spatial resolution is 12.5 m. This satellite data was applied to extract the drainage and lineament across the study area, Jaboi Sabang. Satellite and ground temperature data were processed and analysed using the Envi 5.3, PCI Geomatica 2016 and ArcMap 10.4 softwares, while the rest of supporting data were interpolated using ArcMap 10.4. All of the results from each data were integrated to produce a map shows geothermal potential

### 3. Result and Discussion

Satellite Landsat 8 image on July 18th, 2017 were used for LST retrieval and land cover classification and ALOS PALSAR DEM on January 3rd, 2009 were used for lineament and surface drainage extraction. The Envi 5.3

and PCI Geomatica 2016 software used for processing satellite data. All the processed data were displayed with digitized fault lines and hot spring locations based on the available geological map. The land surface temperature retrieved from Landsat-8 as show in Fig. 3. The temperature ranges are 22 to 29°C. The figure shows several locations with high temperatures over than 26°C. Some of the locations have manmade objects (urban areas) which are capable to give relatively high temperature when monitored by the satellites, therefore, not all of them were considered as geothermal potentials site (Zhang *et al.* 2012). Land covers classification of four classes, showing openbare land, urban/plantation area, vegetation and water over the study area were obtained from the Landsat 8 image. Lineament extraction as indicator for possible faults or cracks (Fig. 4(a)) and surface drainage showing four orders of stream (Fig. 4(b)) over the study area were obtained from the ALOS PALSAR DEM data.

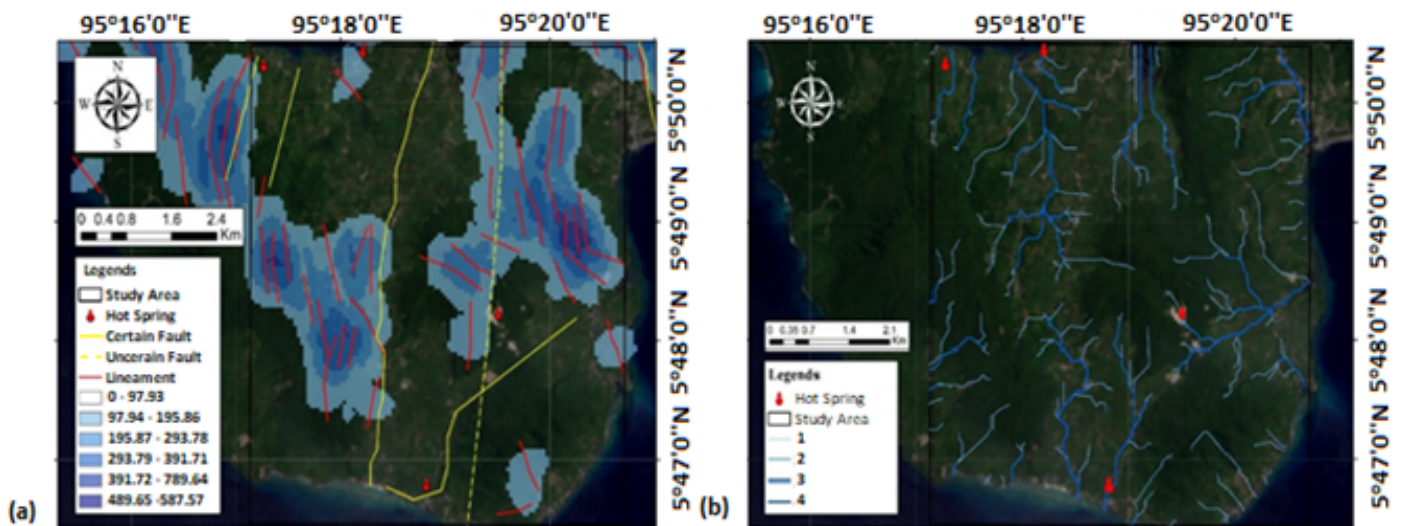


Fig. 4 (a) Lineament extraction and (b) surface drainage

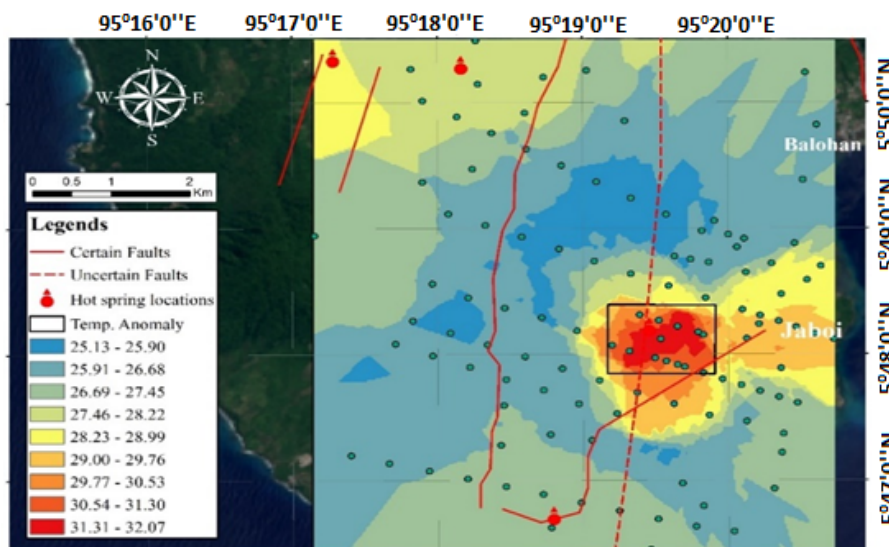


Fig. 5 Temperature distribution from ground measurements

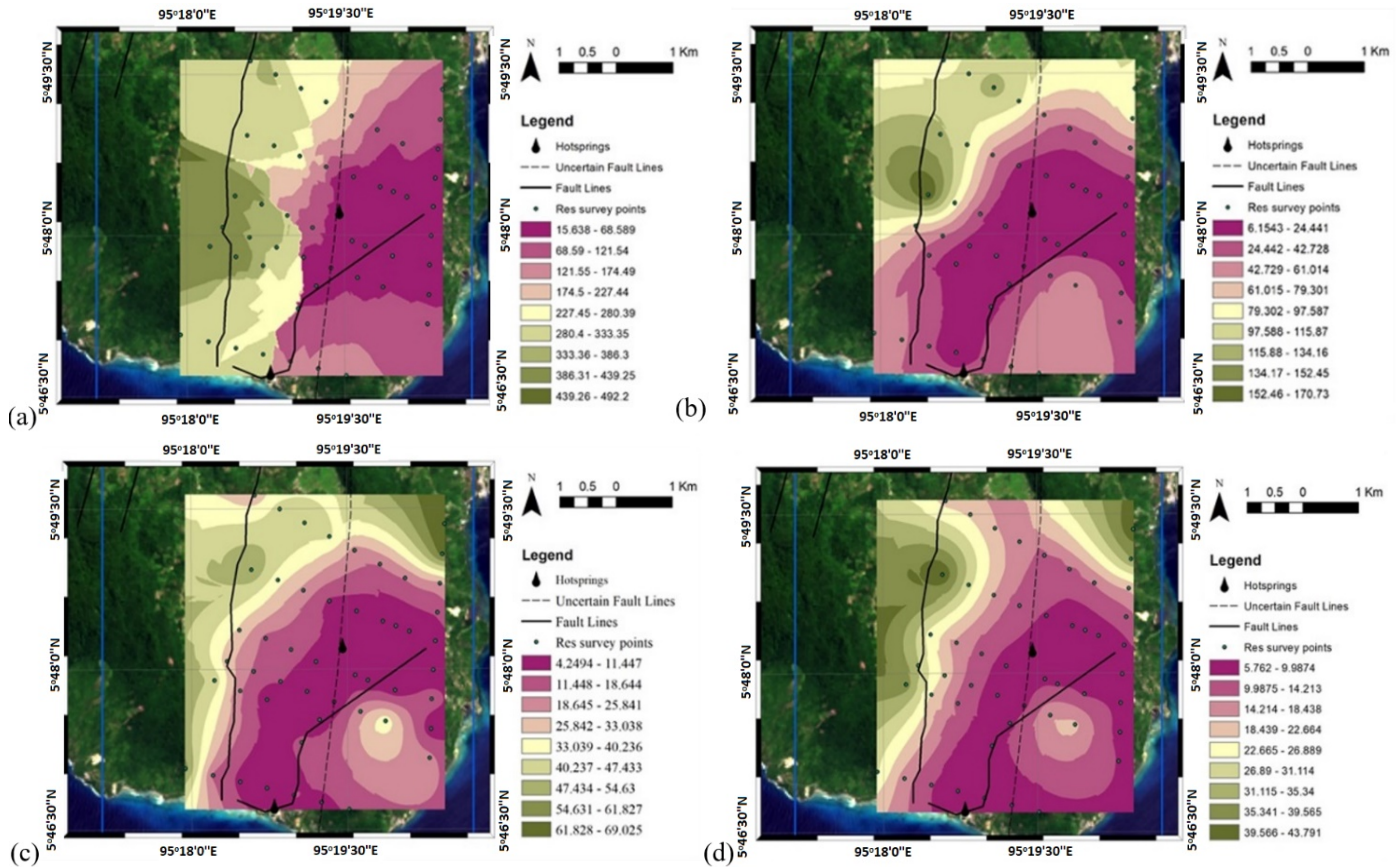


Fig. 6 The resistivity distribution across the study area of different depth (a) at 250 m depth, (b) at 500 m depth, (c) at 750 m depth and (d) at 1000 m depth.

Two supporting datasets were used to validate the retrieval data from remote sensing. First dataset was ground temperature measurements with total 114 points evenly distributed around the study area with temperature distribution varies in range of 25 to 32°C (Fig 5). Second dataset was vertical electrical sounding of Wenner array type with total of 51 survey points showing four different the trajectory of 250, 500, 750 and 1000 m (Fig. 6). Based on the integration of the obtained information, four areas

were determined that have potential for geothermal, mark by number 1, 2, 3 and 4 (Fig. 7(a)). Areas 1 and 3 show high possibility for geothermal activity in the subsurface, where both have all the features even though lineaments are sparse. Areas 2 and 4 show moderate possibility in term of geothermal potential due to lack of related features. Area 2 has moderate LST, sparse drainage and no lineament in the area.

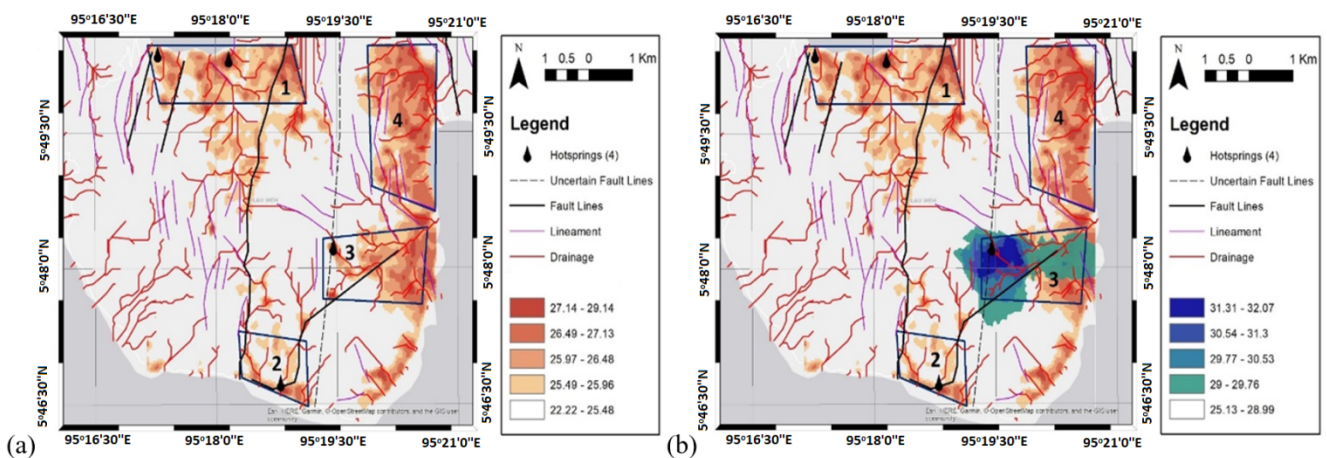


Fig. 7 (a) Integration information obtained from remote sensing data across the study area, and (b) from remote sensing and ground temperature measurement



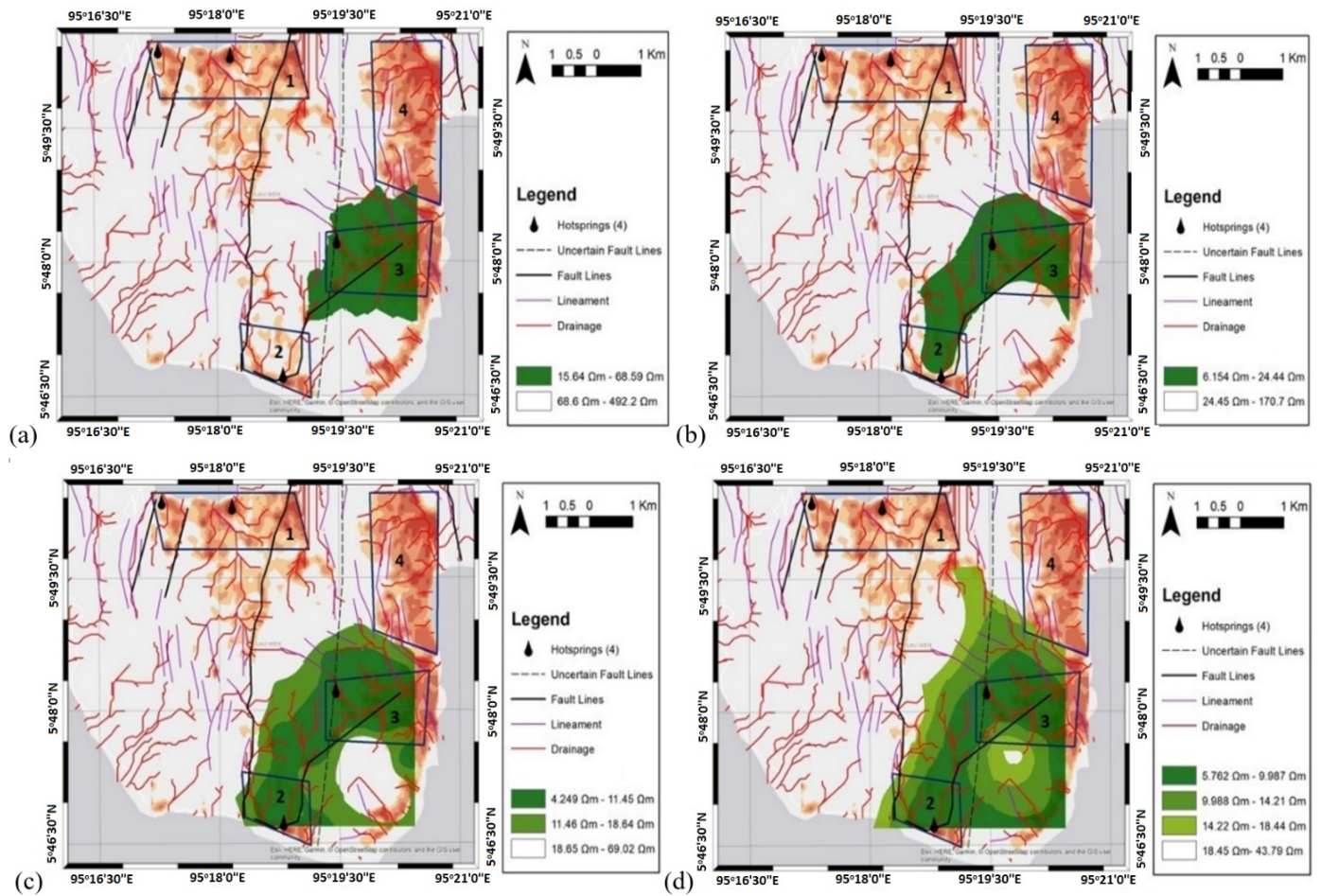


Fig. 8 Integration of obtained information from remote sensing and resistivity of distance (a) at 250 m (b) at 500 m, (c) at 750 m, and (d) at 1000 m.

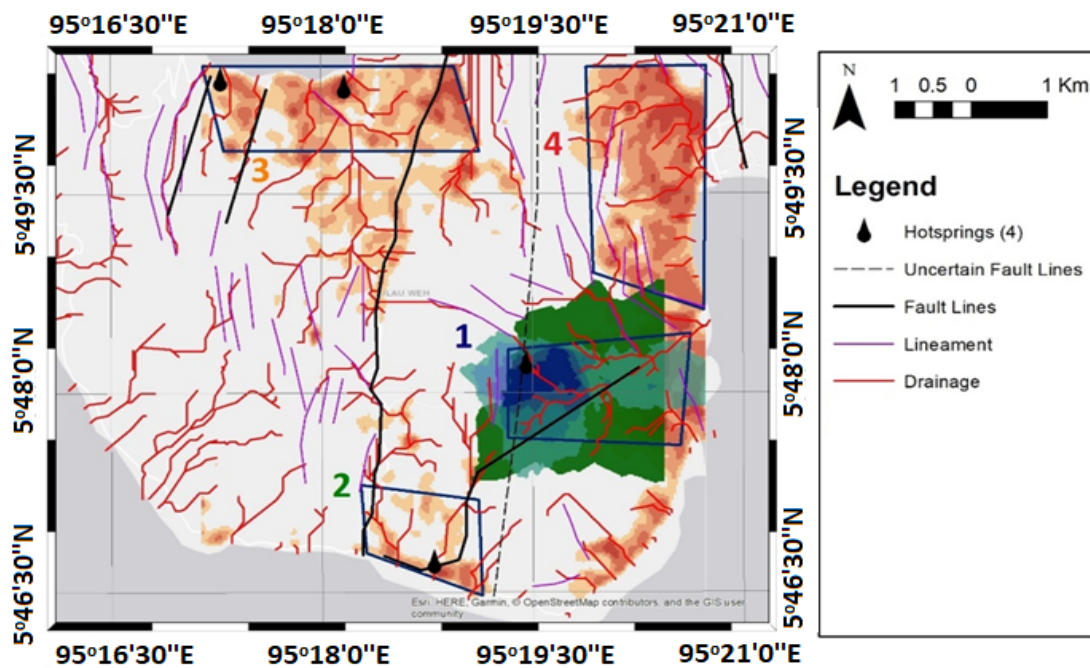


Fig. 9 Ranking for the potential of the four areas

**Table 1**

Features of interest of the potential areas based on all the available datasets

Potential Area		1	2	3	4
<b>Remote Sensing</b>	Temperature	High	Moderate	High	High
	Drainage	Dense	Sparse	Dense	Dense
	Lineament	Sparse	None	Sparse	Dense
	Fault	√	√	√	×
	Manifestation	√	√	√	×
<b>Ground Measurement</b>	Heat Anomaly	×	×	√	×
<b>Low Resistivity</b>	250 m	×	×	×	×
	500 m	×	√	√	×
	750 m	×	√	√	×
	1000 m	×	√	√	×

Moreover, area 4 has no fault according to the available geological map and no manifestation on the surface. Figure 7(b) shows the information obtained from remote sensing method and ground temperature measurement survey overlaid on top of each other. Areas with temperature of 29°C and below are omitted for easy viewing when overlaid on top of LST. From ground measurement, a heat anomaly was found coinciding with potential area number 3. Resistivity values could correspond to geological features such as clay, alluvium, sand, fresh groundwater, shale and sandstone (Lichoro *et al.* 2017, Noorollahi *et al.* 2008) that for geothermal reservoirs the resistivity value is approximately 10 Ωm. A geothermal with high clay content and high temperature contribute to a decrease in resistivity. Figure 8 shows the integration of resistivity distribution in the study area with information obtained from remote sensing. The survey conducted was not wide enough to cover all the study area resulting in the resistivity distribution covering only. Table 1 gives information of all the areas with geothermal potential from all of the available datasets. From the table, it can be seen that area 3 has all the features of interest in spite of sparse in lineament. The potential areas were ranked according to several factors regarding the features that are clustered within the area (Fig. 9).

#### 4. Conclusion

Sabang has the prospect for geothermal exploration based on the existence of surface manifestations around the area. This study has applied remote sensing technique utilizing various sensors aboard the satellites to determine the potentiality for geothermal. The results have been validated by integrating it with supporting data, such as geological map in the present study, ground temperature measurement and VES. Its integration produced four areas which were considered to have high geothermal potential. Moreover, these areas vary in term of the clustering of the features of interest, such as lineament and drainage density, high surface temperature, hot spring existence, fault existence and the low resistivity subsurface. These features must take into consideration. Ranking for potential area were made to decide which area has the most potential. Area potential 3 has the highest potential for geothermal with most of the

related features clustering in the area, followed by areas 2, 1 and 4. Finally, roadmaps of geothermal potential in the present study were successfully created as an insight for future reference.

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