

Geological Mapping Optimisation Using Satellite Gravity, Satellite Imagery, and Seismic Shear Velocity (Vs30) to Monitor Lithological Condition in Geothermal Area of Mount Salak, West Java

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Abstract. Conventional geological mapping has several challenges such as limitation of area coverage, tough terrain, unstable weather condition, high-cost survey, also limitation of expert geologist that capable to do geological mapping. Remote sensing is an alternative solution to geological mapping through the combination of satellite gravity, satellite imagery, and seismic shear wave velocity. This research aims to optimise geological mapping activity in the Mount Salak geothermal area from ineffective area coverage mapping and inefficient budgeting allocation. Integration of rock density from satellite gravity, lithological distribution from satellite imagery, and seismic shear wave velocity from Vs30 are giving more detailed lithological units interpretation with specific physical conditions. There are two main area of Mount Salak that should be preserved geothermal resource sustainable. Northeast area needs to preserve heat source and groundwater recharge area, that consist of dense vegetation as landcover, relatively high rock density value (2.30 - 2.50 gr/cm³), high seismic shear wave velocity (600 – 900 m/s), also dominantly covers by Andesitic-Basaltic Lava. Southwest area preserve reservoir and caprock of geothermal conceptual model, where covers by dense vegetation with several bare land as geothermal wells and powerplants, relatively low rock density value (2.00 – 2.20 gr/cm³), moderate seismic shear wave velocity value (450-750 m/s), also dominated by several pyroclastic product such as Lapilli and Tuff. This research shows good indication in geothermal resource preservation in the Mount Salak, that keep natural aspect of geothermal conceptual model still preserved well.

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1 Introduction

Geological mapping is the activity to identify spatial distribution of lithological units that are spreading in the research area. Conventional geological mapping commonly used ground-check survey to acquisition of rock sampling and other lithological structure that can be support the mapping process [1, 2]. This conventional mapping method has an advantage such as acquisition data has a high accuracy and more representative with actual field condition [3–5]. Nevertheless, there are several disadvantages that cannot be separated from conventional geological mapping data acquisition method, in example limitation of area coverage, tough terrain, unstable weather condition, high-cost survey, also limitation of expert geologist that capable to do geological mapping [6–8].

In geothermal area, geological setting has an important role to determine drilling and powerplant optimal location [6]. Geological condition relatively static in long time, except there are massive geological process in the area [9]. However geological condition is static, there are several possible cause that change the geological setting in the geothermal prospect area, in example change of alteration zone form because of hot groundwater switch the run-off direction, long dormant-time in the vulcanological process, and/or massive geological deformation in the geothermal prospect area [10–12]. These problems need monitoring and evaluation in periodically time to ensure geological extraction process run smoothly with low risk on land degradation.

Remote sensing method is one of alternative solution to solve the geological mapping challenge. Remote sensing is using wide-range area data acquisition from satellite vehicle that orbit in the earth atmosphere [13–15]. With wide-scale area covered, remote sensing potentially solves the limitation area covered in conventional geological mapping [16, 17]. Satellite gravity and satellite imagery method can be remote sensing method that possible to do geological mapping in the form of lithological unit interpretation [18, 19].

Satellite gravity is implementing gravity anomaly distribution measurement to calculate the rock density [20, 21]. Simply, satellite gravity was worked similar with terrestrial gravimeter, but for this one was attached in satellite vehicle [22, 23]. Reciprocally with satellite imagery that was utilised satellite vehicle as carrier to orbit the earth [24, 25]. Satellite imagery was occurred earth surface condition in periodical time-range, where relatively more updated than satellite gravity data that relatively static [26, 27].

These two methods of remote sensing will be completed with seismic shear wave velocity 30-meters beneath the surface (V_{s30}). V_{s30} provide spatial lithological information in the context of rock stiffness [26, 28]. Higher stiffness related to harder and relatively high-compact lithological condition, vice versa [28, 29]. Theoretically, V_{s30} should be related with rock density that was occurred from satellite gravity [30]. This approach can be optimised the geological mapping from remote sensing methods.

This research aims to optimise geological mapping activity, in the context of solving conventional mapping that was related to area coverage and inefficient budgeting allocation. This research was conducted in Mount Salak in West Java Province, Indonesia. Figure 1 shows the area of this research. This area was famous with geothermal manifestation and there are several geothermal powerplant already producing electricity. So, this area would be great example of remote sensing method application as geological mapping optimisation in geothermal prospect area.

2 Research Method

Several data in this research are open-access data, such as Global Gravity Model Plus (GGMPlus) for satellite gravity model [31], Landsat 8 Operational Land Imager (OLI) Level 2 for satellite imagery [32], and V_{s30} data for seismic shear wave velocity [33]. GGMPlus

need some data corrections and upward continuation before inversion to occur rock density distribution [6]. Landsat 8 OLI Level 2 provide earth surface condition that need quantification and remote sensing reflectance calculation, before calculating the composite band ratio and reclassification to interpret the lithological distribution from imagery [6]. Vs30 exactly already provide seismic shear wave in the 30-meters depth beneath the earth surface [33]. These data will be combined and validated with regional geological information to ensure the research result will be representative. Figure 2 shows flowchart of this research which provide step-by-step data processing, analysis, and result of the research.

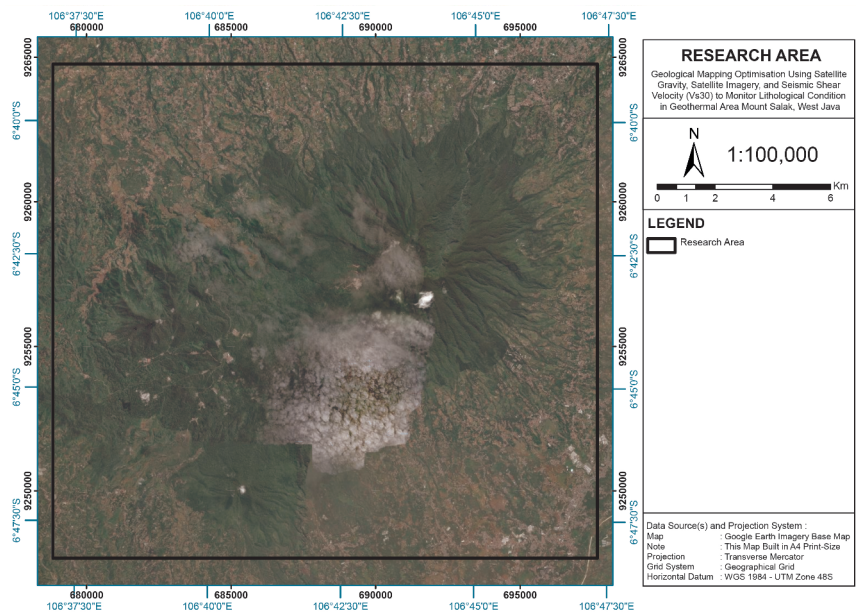


Fig. 1. Research location in the Mount Salak and its surrounding area.

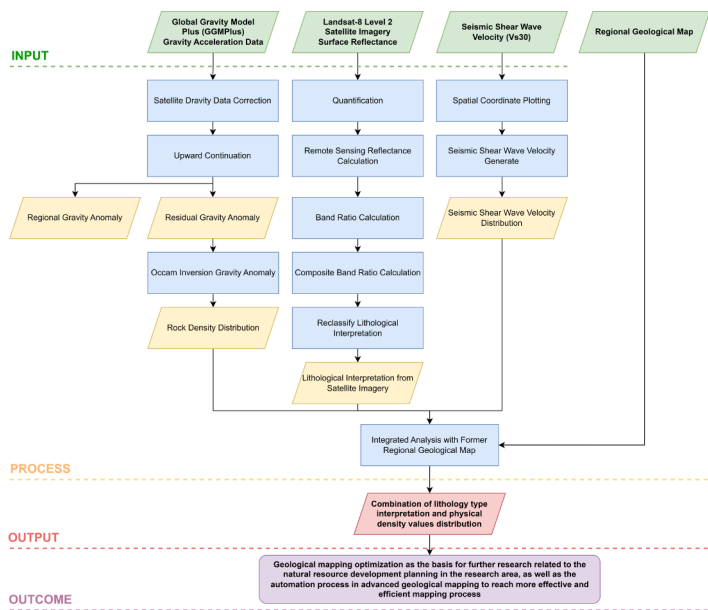


Fig. 2. Research flowchart.

3 **Research Results**

The research processing produced 2 maps from remote sensing methods and a map from Vs30 values distribution. Figure 3 shows the GGMPlus satellite gravity model processing produces density values distribution in Mount Salak with the range value of 2.00 – 2.60 gr/cm³. Relatively lower range value of rock density (2.00 – 2.25 gr/cm³) are distributed in the northeast, southwest, and outermost research area’s perimeter. Relatively higher range value of rock density (2.40 – 2.60 gr/cm³) are concentrated at the northwest and southeast of Mount Salak.

Figure 4 shows the Landsat-8 OLI Level 2 satellite imagery processing produces the lithological imagery interpretation of Mount Salak in 10 classes. Pyroclastic Fall Deposits with Lava Flow 5 (PFaLF15) was identified as youngest lithology layer is distributed in the peak of Mount Salak and several spots on the river flow networks because of erosion. The oldest lithology layer known as Pyroclastic Fall with Lava Flow 1 (PFaLF11) is distributed at the outermost research area and several spots on the eroded mountain slope.

Figure 5 depict Vs30 spatial distribution in the Mount Salak area with the range value of 300 – 900 m/s. The lithology with stiffer characteristics is dominated the body of Mount Salak, especially at the northwestern part of research area with relatively higher seismic shear wave velocity (750 – 900 m/s). In the geothermal exploitation area at the southwestern part of Mount Salak, the seismic shear wave velocity was identified lower with the range value of (300 – 500 m/s). Table 1 display a description of the acronyms for naming lithological units in Figure 4, also the density values range and seismic shear wave velocity for each interpreted lithological type.

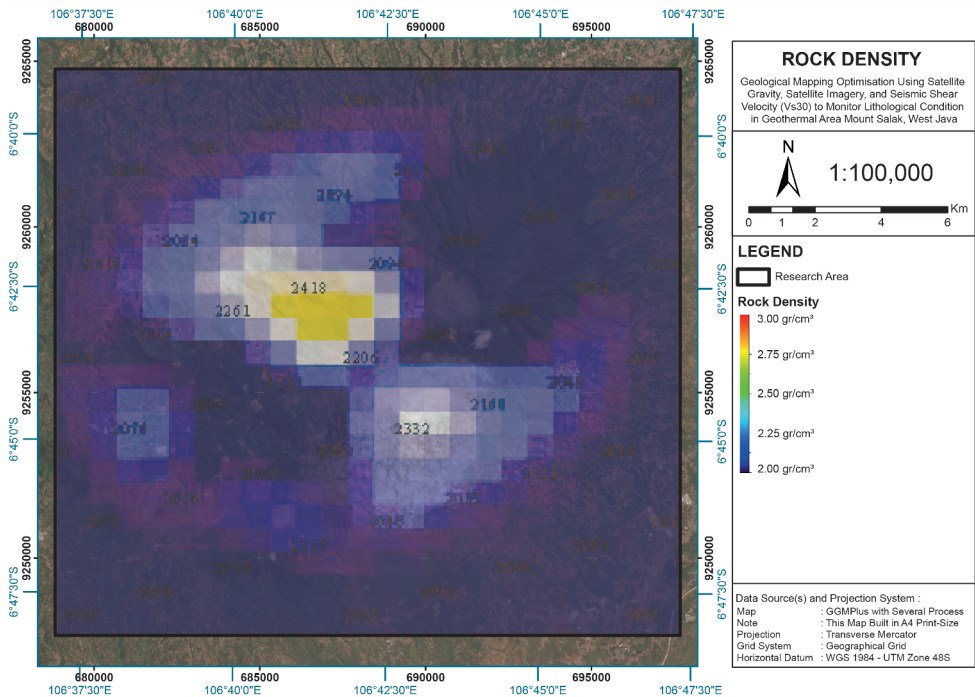


Fig. 3. Rock density value distribution in the Mount Salak and its surrounding area.

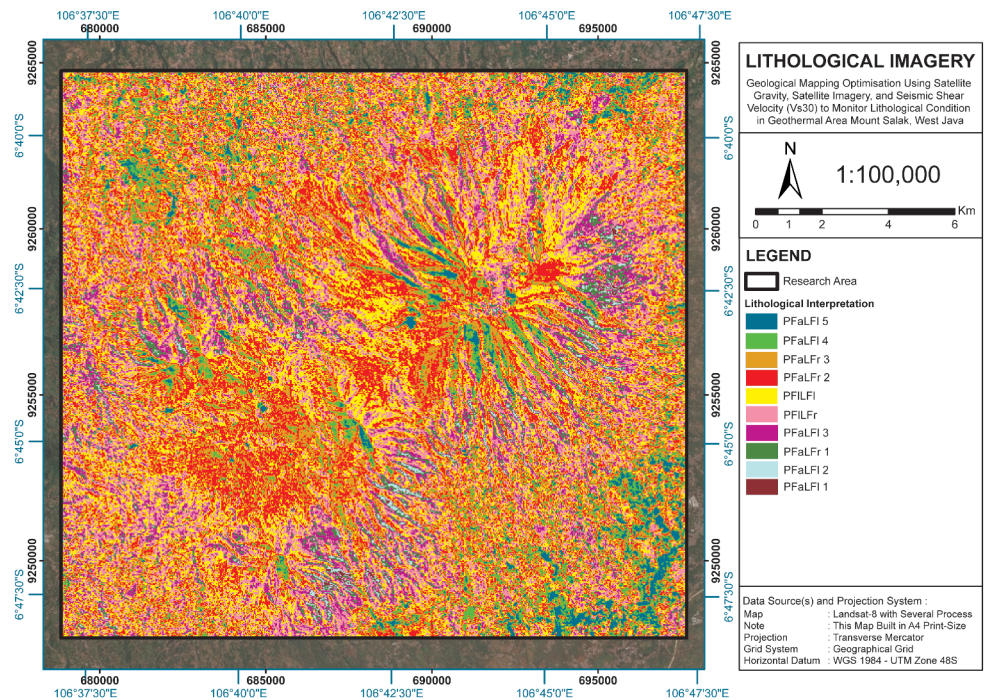


Fig. 4. Lithological unit distribution in the Mount Salak and its surrounding area.

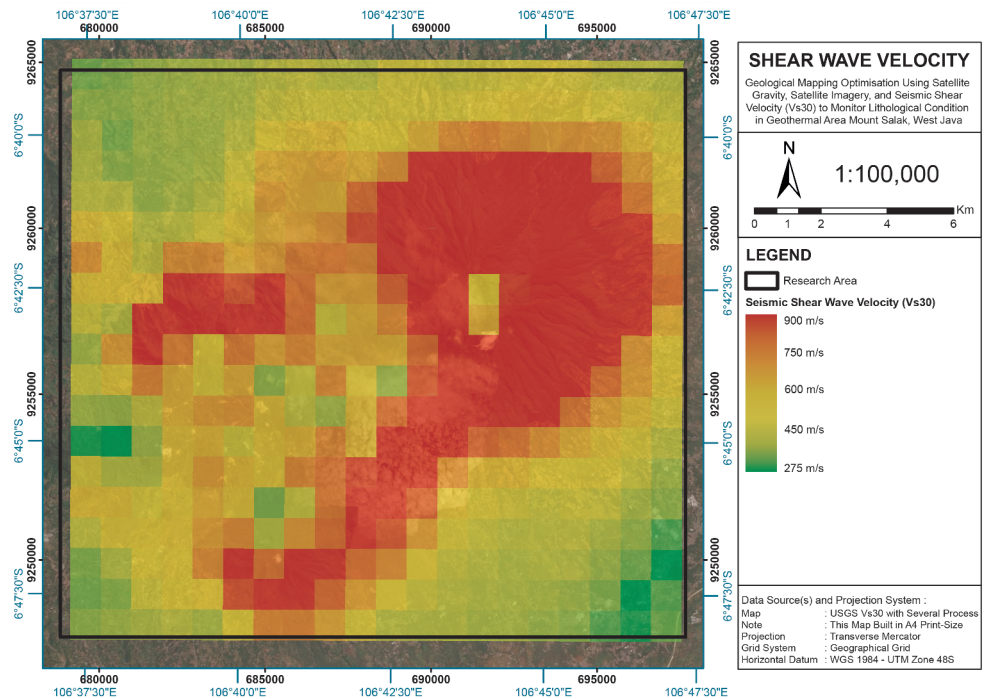


Fig. 5. Seismic shear wave velocity distribution in the Mount Salak and its surrounding area.

Table 1. Lithological unit interpretation in the Mount Salak description with calculated density value range and interpreted seismic shear wave velocity value.

Initial	Lithological Type	Description	Rock Density (gr/cm ³)	Seismic Shear Wave Velocity (m/s)
PFaLF15	Pyroclastic Fall Deposits with Lava Flow	Andesitic-Basaltic Lava, Tuff Pumice, Lahar, Lapilli	2.20 - 2.50	450 - 900
PFaLF14	Pyroclastic Fall Deposits with Lava Flow	Tuff Pumice, Lava fragment implied, Andesitic Lava	2.20 - 2.40	450 - 900
PFaLFr3	Pyroclastic Fall Deposits with Lava Fragment	Volcanic Breccia, Lava fragment implied	2.10 - 2.20	500 - 700
PFaLFr2	Pyroclastic Fall Deposits with Lava Fragment	Tuff, Tuff Pumice, Andesitic Lava fragment implied	2.00 - 2.10	450 - 600
PFILF1	Pyroclastic Flow Deposits with Lava Flow	Tuff Breccia, Lapilli, Tuff, Andesitic Lava	2.00 - 2.10	400 - 700
PFILFr	Pyroclastic Flow Deposits with Lava Fragment	Lapilli, Lahar, Tuff, Tuff Pumice, Andesitic Lava fragment implied	2.00 - 2.15	300 - 500
PFaLF13	Pyroclastic Fall with Lava Flow	Tuff Breccia, Lapilli, Lahar, Tuff Pumice, Volcanic Breccia, Andesitic Lava fragment implied	2.00 - 2.10	400 -600
PFaLFr1	Pyroclastic Fall with Lava Fragment	Tuff Breccia, Lapilli, Lahar, Andesitic Lava fragment implied	2.00 - 2.20	500 - 750
PFaLF12	Pyroclastic Fall with Lava Flow	Tuff Breccia, Volcanic Breccia, Andesitic-Basaltic Lava	2.20 - 2.40	600 - 800
PFaLF11	Pyroclastic Fall with Lava Flow	Volcanic Breccia, Tuff Pumice, Lapilli, Andesitic-Basaltic Lava	2.25 - 2.40	600 - 900

4 Discussion

Rock density and seismic shear wave velocity related to compactness and consolidated level of lithological unit those are interpreted from satellite imagery data processing. Rock density in the research area shows high rock density values (2.30 - 2.50 gr/cm³) distribution in the central area of Mount Salak which gradually downward to the northwest and southeast of research area. In the southwestern area, there is area with rock density was identified in the value of 2.20 gr/cm³, where several geothermal wells and powerplants located. These geothermal wells related to the location of geothermal reservoir and how geothermal conceptual model prediction work in Mount Salak area.

If we try to figure out the geothermal conceptual model, it is related to high density zone in the centre of research area potentially became heat source rock location. Higher elevation is suited to take a role as recharge area of Mount Salak groundwater system. It is supported by Vs30 value distribution in the center and northeast of research area that dominated with high value of seismic shear wave velocity (600 – 900 m/s). Lithological units such as Andesitic Lava and Andesitic-Basaltic Lava are giving an indication about the type of heat source rock, that potentially formed from intermediate type of magmatic differentiation.

This situation potentially made groundwater percolation running to southwest and brought hot geothermal fluid into nowadays geothermal wells powerplants area. Geothermal wells area it is known surrounded by moderate seismic shear wave velocity (450 – 750 m/s) with low rock density value (2.00 - 2.20 gr/cm³). It is indicating stiff rock with several high porosity in the formed of potential lithological unit, such as Tuff Breccia, Tuff Pumice and

Lapilli. This lithological interpretation also interpreted spread onto this area, where geothermal wells and powerplants area dominated by Pyroclastic Fall Deposits with Lava Fragment 2 (PFaLFr2) and Pyroclastic Flow Deposits with Lava Flow (PFLFl). These two lithological units consist of Tuff Breccia, Tuff Pumice, and Lapilli, which are predicted became geothermal reservoir rock. Abundant of Tuff as caprock of geothermal reservoir in the same area made the prediction stronger, if the area is the geothermal reservoir area that must be preserved to keep geothermal resources sustainable.

If we give some concerns in the natural satellite imagery in the Figure 1, it is known if there are dense vegetation covers dominant area of Mount Salak landcover rather than bare land and cultivated land, especially in the northeastern part of Mount Salak. This is a good indication when we know from this research if the area has potentially become recharge area of geothermal fluid system and heat source for geothermal resource in the Mount Salak area. This northeastern part area should keep preserved to support geothermal resource extraction in the southwest. The southwestern area where geothermal resource extraction happened, also need to preserve geological aspects of reservoir and caprock. If there are damaged in geothermal conceptual model in Mount Salak, potentially will be disturbance in geothermal resource of Mount Salak.

5 Conclusion

From these analysis and interpretation, there are two important area of Mount Salak that should be preserved to keep geothermal sustainable in this area. Northeastern area needs some concern to preserve heat source and groundwater recharge area, and southwestern area concern to preserve reservoir and caprock of geothermal conceptual model. Northeastern area has dense vegetation as landcover, relatively high rock density value ($2.30 - 2.50 \text{ gr/cm}^3$), high seismic shear wave velocity ($600 - 900 \text{ m/s}$), also dominantly covers by Andesitic Lava and Andesitic-Basaltic Lava. Southwestern area covers by dense vegetation with several bare land as geothermal wells and powerplants, relatively low rock density value ($2.00 - 2.20 \text{ gr/cm}^3$), moderate seismic shear wave velocity value ($450-750 \text{ m/s}$), also dominated by several pyroclastic product such as Tuff Breccia, Tuff Pumice, Lapilli, and Tuff. The result of this research shows good indication in geothermal resource preservation, that keep natural aspect of geothermal conceptual model still preserved well.

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