Preliminary study of near surface detections at geothermal field using optic and SAR imageries

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Abstract. Current remote sensing technologies shows that surface manifestation of geothermal system could be detected with optical and SAR remote sensing, but to assess target beneath near the surface layer with the surficial feature needs a further study. This study conducts a preliminary result using Optic and SAR remote sensing imagery to detect near surface geothermal manifestation at and around Mt. Papandayan, West Java, Indonesia. The data used in this study were Landsat-8 OLI/TIRS for delineating geothermal manifestation prospect area and an Advanced Land Observing Satellite(ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR) level 1.1 for extracting lineaments and their density. An assumption was raised that the lineaments correlated with near surface structures due to long L-band wavelength about 23.6 cm. Near surface manifestation prospect area are delineated using visual comparison between Landsat 8 RGB True Colour Composite band 4,3,2 (TCC), False Colour Composite band 5,6,7 (FCC), and lineament density map of ALOS PALSAR. Visual properties of ground object were distinguished from interaction of the electromagnetic radiation and object whether it reflect, scatter, absorb, or and emit electromagnetic radiation based on characteristic of their molecular composition and their macroscopic scale and geometry. TCC and FCC composite bands produced 6 and 7 surface manifestation zones according to its visual classification, respectively. Classified images were then compared to a Normalized Different Vegetation Index (NDVI) to obtain the influence of vegetation at the ground surface to the image. Geothermal area were classified based on vegetation index from NDVI. TCC image is more sensitive to the vegetation than FCC image. The later composite produced a better result for identifying visually geothermal manifestation showed by detail-detected zones. According to lineament density analysis high density area located on the peak of Papandayan overlaid with zone 1 and 2 of FCC. Comparing to the extracted lineament density, we interpreted that the near surface manifestation is located at zone 1 and 2 of FCC image.

1. Introduction
Preliminary survey is the earliest part in geothermal exploration. In this stage of exploration, the geologists map the prospect area to determine it’s geological setting as early recognition of the geothermal system. The results of this survey are geological and surface manifestation map that can be applied to determine the focus area for next exploration and early prediction of the geothermal system that occurred in that area.
Geological mapping in geothermal exploration usually begins with remote sensing study to reduce the cost of field investigation [1]. This study used optical and Synthetic Aperture Radar (SAR) images. Optical image is a remote sensing imagery that use electromagnetic radiation from optical wavelength (visible, near infra-red, short infra-red, and thermal infra-red). On the other hand, SAR image use microwave wavelength. Each image type has its advantageous and disadvantageous in the exploration. Optical image can be used to detect alterations related to hydrothermal activity even though the result will be limited by its low grade, area, erosion and scattered distribution of exposed surface manifestation due to vegetation cover, even though data from vegetation backscattering can provide alteration information with particular signal [2]. On the contrary, the SAR back-scattering intensity data represents the power return to the satellite as function of several surface parameters such as roughness, gradient slope, magnetic, and dielectric property of the ground regardless atmospheric condition [2]. This study conducts remote sensing analysis using both image to produce a low cost, easily understood preliminary study of near surface manifestation in Papandayan geothermal field, Garut, West Java, Indonesia.

Papandayan geothermal field located in Garut District, West Java, Indonesia has been selected as study area because there is some existence of geothermal manifestations from volcanic system (figure 1) in the form of extensive alteration, high temperature fumarole, and hot springs on the surface [3]. Papandayan is an “A” type volcano in Indonesian classification, which means this volcano has eruption history after 1600 [4][5]. The latest eruption noted in 2002 produced phreatic - phreatomagmatic eruption [3]. Those volcanic activities affirm that there is possibility of geothermal system below the surface of Papandayan area. There is a possibility that not all thermal manifestation can proceed to the surface due to the lithology, structural, or vegetation coverage boundary. Therefore, this research will give a preliminary study of geothermal near surface manifestation that will be useful to asse geothermal potential development in Papandayan.

![Location map of study area at Mt. Papandayan, West Java, Indonesia presented by black rectangle overlaid on DEM SRTM 30 m.](image)
2. Data Collection and Processing

We used Landsat-8 OLI TIRS and SAR images in this study. The acquisition date of Landsat-8 OLI TIRS is 6 September 2016. The radiometric calibration, atmospheric correction, and geometric correction were applied before visual interpretation using ENVI 5.2 software.

Radiometric calibration is a process to improve image quality by converting digital number to radiance for further processing. Then the process was followed by an atmospheric correction to reduce atmosphere effect and convert the radiance to the reflectance. We used the Fast Line of sight Atmospheric Analysis of Spectral Hyperubes (FLAASH) to reduce atmospheric effect in the image. The FLAASH is a module in ENVI software to correct the effect of water vapor, oxygen, carbon dioxide, methane, ozone, molecule, and aerosol distribution in the atmosphere [6] as cited [7]. The geometric correction was also applied to locate pixel image into referenced coordinate system. Corrected and calibrated optic image was used to recognize the geothermal surface manifestation. The geothermal surface manifestation recognition was performed based on visual interpretation to the texture, tonal, and colour in the True Colour Composite (TCC) RGB for band 4,3,2 and False Colour Composite (FCC) RGB for band 5,6,7 (figure 2A and 2B). The identified geothermal surface manifestations were then compared to Normalized Different Vegetation Index (NDVI) image to obtain the vegetation condition at the ground surface. Geothermal potential area was interpreted to the area with low vegetation cover tendency as a result of heat from below the surface [8].

![Image](a)
Figure 2 True Color Composite (TCC) RGB for band 4,3,2 at Mt. Papandayan and surrounding area (a) and False Color Composite (FCC) RGB for band 5,6,7 (b) showed that TCC image represents actual color compared FCC image have better visualization of surface condition with better contrast and clearer texture.

We also used the SAR image for analysing near surface structures in this study. Advanced Land Observing Satellite (ALOS) Phased Array L-type Synthetic Aperture Radar (PALSAR) images level 1.1 were selected due to long wavelength (=23.6 cm) and capability to reduce the canopy vegetation effect [9] with detail information of the data is listed in table 1.

| No | Data Type       | Orbit       | Date    |
|----|-----------------|-------------|---------|
| 1  | Dual Polarization | Descending  | 10/6/07 |
| 2  | Dual Polarization | Descending  | 10/6/07 |
| 3  | Dual Polarization | Ascending   | 19/10/08|
| 4  | Dual Polarization | Ascending   | 19/10/08|

ALOS PALSAR image processing including radiometric calibration, multi-looking, polarimetric, and geometric correction were applied using Sentinel Application Platform (SNAP) software.
Radiometric calibration function is to correct SAR image so that the produced pixels values are represent the real backscatter from earth reflection [10]. Multi-looking is calibration process to improve the image focus. This step is necessary to enhance the image quality and transformed into Single Look Complex (SLC) data [1].

Geometric corrections in SNAP software are including ALOS deskewing to transform reversed geometry of ALOS 1.1 image into Doppler geometry and terrain correction for geocode the image by correcting SAR geometric distortion with digital elevation model (DEM) and create map projection. Corrected ALOS PALSAR image was used to analyse geological structure and lineament density in ascending and descending orbits of ALOS PALSAR Images as depicted by figure 3 [1].

Figure 3 Images of ALOS-PALSAR ascending (a) and descending (b) orbits show surface feature in opposite Line of Sight (LOS).
3. Detected Near Surface Manifestation

3.1 Geothermal Surface Feature on Landsat-8 OLI TIRS
Remote sensing imagery has various bands with different wavelength. Theoretically, the longer a band’s wavelength it makes a better penetration into the earth [11]. Detection of surface manifestation using TCC (figure 2a) of Landsat 8 data shows 6 zonation according to its RGB color (figure 5) with reflectance value detail in table 2. According to the delineation could be seen that TCC image can differentiate surface feature quite well by its visual, but still can’t differentiate the manifestation and cloud that shows same color.
Table 2 Reflectance value of TCC for the classified geothermal surface feature zones

| Zone | Reflectance | Reflectance | Reflectance |
|------|-------------|-------------|-------------|
|      | R (Band 4)  | G (Band 3)  | B (Band 3)  |
|      | Min | Max | Min | Max | Min | Max |
| 1    | 0.003698 | 0.016398 | 0.005432 | 0.017202 | 0.007629 | 0.019887 |
| 2    | 0.004721 | 0.025978 | 0.006080 | 0.024120 | 0.008372 | 0.023749 |
| 3    | 0.004332 | 0.011643 | 0.005819 | 0.012078 | 0.008096 | 0.011458 |
| 4    | 0.003722 | 0.041292 | 0.005568 | 0.038431 | 0.007912 | 0.036169 |
| 5    | 0.003550 | 0.014269 | 0.005228 | 0.014023 | 0.007535 | 0.014548 |
| 6    | 0.003642 | 0.018908 | 0.005388 | 0.015928 | 0.008084 | 0.014602 |

Figure 4 Work flow of optical and Synthetic Aperture Radar (SAR) remote sensing data processing and methodology.
Meanwhile detection of surface feature using FCC of Landsat 8 data shows 7 zones (figure 6) with detailed reflectance value mentioned in table 3. Based on delineation of FCC image, it shows different result with TCC image where FCC composite image has more zonation than TCC image. It proved that FCC shows texture, tone, and color better for visualization of surface feature zonation.

Table 3 Reflectance value of FCC for the classified geothermal surface feature zones.

| Zone | Reflectance               |       |       |       |       |
|------|---------------------------|-------|-------|-------|-------|
|      | R            | Max    | G       | Max    | B       | Max    |
| 1    | 0.008879     | 0.043441 | 0.004585  | 0.030404 | 0.002382  | 0.021748  |
| 2    | 0.008128     | 0.041081 | 0.005343  | 0.028651 | 0.003318  | 0.018798  |
From optic image surface feature delineation, target of surface manifestation in Mount Papandayan geothermal field categorized as zone 1, 2 and 3 according to its color, tone, and texture. Zone 1 in TCC have a wider cover area than zone 1 in FCC. On the other hand, zone 2 and 3 both images show different shape and location because of different color and texture. Comparison of both composites shows that FCC has more precise delineation than TCC for detect surface manifestation.
Based on NDVI analysis compared with TCC, low vegetation zone assembled in the peak of Mt. Papandayan, particularly in Tegal Alun-alun Crater, Mas Creater, Manuk Creater and in the north-east side of NDVI map (figure 7). Rare vegetation zone was marked with black rectangle while cloud coverage marked with white rectangle. Rare vegetation could be caused by hydrothermal activity from geothermal system beneath the ground. According to earlier geological study [3] areas marked with black rectangles in NDVI map is the location of altered ground and fumaroles from Papandayan hydrothermal activity. Except in the Papandayan peak, none of surface manifestations were found in the other area.

Figure 7 Image of TCC Landsat 8 OLI TIRS Band 4,3,2 of Mount Papandayan and surrounding area overlaid to NDVI map. Black rectangles are rare vegetation zone and white rectangle represents cloud coverage zone.
3.2 Near Surface Structure on ALOS PALSAR  
Ridges morphology is one of geological structure feature. Geological structure makes the effected rock get weaker and create valley because of intensive erosion. In the other hand, ridges created from resistant rock that not effected by the erosion, or because of fold structure. Lineament study of ridges in Papandayan field (figure 8A) generate LLD map (figure 8B) overlaid with main structure according to geological map[12] reveal that geological structures happened to be located at low – high line density area. That area also be the place where of geothermal manifestation found. LLD analysis shows that high lineament density does not always show high structural activity.

Comparison between LLD map with optical visual study reveal that zone 1 in TCC and FCC composite overlaid with mostly high lineament density area, while zone 2 in both image overlaid with geological structure and surface manifestation.

![Figure 8](image.png)  
**Figure 8** Detected lineament using ALOS PALSAR in ascending and descending orbit images (A) and lineament density map (B) overlaid with geological structures from regional geological map [7]
3.3 Detected Near Surface Geothermal Manifestation

According to visual analysis of Landsat-8, this remote sensing imagery effectively detected geothermal surface manifestation with FCC image better than TCC. Comparison of visual analysis result of landsat-8 with lineament study of ALOS-PALSAR shows that high lineament density zone of Papandayan and surrounding area does not overlay with particular zone in FCC image delineation. We assumed that lineament density map detects near surface manifestation that cannot be detected with visual analysis. Near surface manifestation may cover with vegetation canopy or surface weathering. According to FCC visual analysis, NDVI and LLD detected near surface geothermal manifestation is located at Manuk Creater, Tegal Alun-Alun Creater, Mas Creater, and papandayan southeast and southwest flank (figure 9). To prove the existence of manifestation near the surface a ground check is necessary.

4. Conclusion

Visual analyses using optical image in Papandayan geothermal field shows that surface feature delineation using RGB composite 5,6,7 (False Color Composite, FCC) is better than RGB composite 4,3,2 (True Color Composite, TCC) presented by its 7 zonation while TCC only have 6 zonation. On the flip side for detecting vegetation coverage on the surface, TCC show a better result than FCC because
of its ability to show real color of surface condition. Green represents vegetation canopy while the other color represents another surface condition.

Figure 9 Near surface geothermal manifestation zone according to FCC visual analysis, NDVI, and LLD marked with white outline.

FCC image have better contrast that makes easier to delineate manifestation near the surface. A longer wavelength of FCC 0.85 – 2.29 μm than TCC 0.45 -0.67μm is predicted to have high penetration into surface layer. On the other hand, visible band with shorter wavelength than short infrared wavelength caused optimum surface layer detection such as vegetation coverage.

The Normalized Different Vegetation Index (NDVI) and visual analysis of TCC indicate low vegetation zone that might related with geothermal activity in mount Papandayan located at Tegal Alun-Alun Creater, Manuk Creater and Mas Creater.

The lineament length density analysis point that some high lineament density area associate with local structure however highest length density doesn’t relate with any structure or geothermal manifestation in the flank of Mount Papandayan. Those high line density zone might come from near surface manifestation that covered with vegetation or weathering.
All things considered that the TCC, FCC, NDVI, and LLD were effective to recognize near surface manifestation of geothermal field in a preliminary state. TCC surface feature delineation that validate with NDVI detected surface manifestation area prospect that associate with low vegetation index. Combination of FCC and LLD provided accurate detection to near surface manifestation zone in geothermal field. The next step of this study is validation with ground check and available geological and geophysical data to validate the result.

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