The Effectiveness of Hydrothermal Alteration Mapping based on Hyperspectral Data in Tropical Region

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Abstract. Hyperspectral remote sensing could be used to characterize targets at earth’s surface based on their spectra. This capability is useful for mapping and characterizing the distribution of host rocks, alteration assemblages, and minerals. Contrary to the multispectral sensors, the hyperspectral identifies targets with high spectral resolution. The Wayang Windu Geothermal field in West Java, Indonesia was selected as the study area due to the existence of surface manifestation and dense vegetation environment. Therefore, the effectiveness of hyperspectral remote sensing in tropical region was targeted as the study objective. The Spectral Angle Mapper (SAM) method was used to detect the occurrence of clay minerals spatially from Hyperion data. The SAM references of reflectance spectra were obtained from field observation at altered materials. To calculate the effectiveness of hyperspectral data, we used multispectral data from Landsat-8. The comparison method was conducted by comparing the SAM’s rule images from Hyperion and Landsat-8, resulting that hyperspectral was more accurate than multispectral data. Hyperion SAM’s rule images showed lower value compared to Landsat-8, the significant number derived from using Hyperion was about 24% better. This inferred that the hyperspectral remote sensing is preferable for mineral mapping even though vegetation covered study area.

1. Introduction
Hyperspectral remote sensing has the potential to provide the detailed physico-chemistry (mineralogy, chemistry, morphology) of the earth’s surface. This capability is useful for mapping and characterizing the distribution of host rocks, alteration assemblages, and minerals. Furthermore, minerals can be uniquely identified based on their spectra [1], [2], [3].

Contrary to the multispectral sensors, the hyperspectral measures targets with high spectral resolution. In particular, the 2.0 to 2.5 μm (SWIR) spectral range covers spectral features of hydroxyl-bearing minerals, sulfates, and carbonates common to many geologic units and hydrothermal alteration [3].

2. Study Area
As an objective of this study, the effectiveness of hyperspectral remote sensing in tropical region was targeted. The Wayang Windu Geothermal Field (WWGF) in West Java, Indonesia was selected as the study area due to the existence of surface manifestation and dense vegetation environment. WWGF is
located about 40 km southwest from Bandung, surrounded by tea plantation with elevation about 1.700
to 2.100 meter above sea level. The land cover of study area is depicted by Figure 1. There are four
portions detected by observing its color which are dark green, green, white-grey, and bright-white. Based
on field observation, the dark green zone correlated with dense vegetation, green is medium vegetation,
white-grey is rare vegetation such as plantation/farm-field, and bright-white is cloud covers. Mt.
Malabar, Mt. Bedil, Mt. Wayang, and Mt. Windu were clearly observed at dense vegetation area as
presented by 1 – 4, respectively.

![Figure 1. True Color Composite (TCC) of Landsat 8 reflectance data for R.G.B= Band 4, 3, 2. Mt. Malabar, Mt. Bedil, Mt. Wayang, and Mt. Windu presented by no. 1 to 4 were clearly observed at dense vegetation area (dark green portion).](image1)

![Figure 2. NDVI Map of study area. Confirming the vegetation covers at study area especially at Mt. Malabar, Mt. Bedil, Mt. Wayang, and Mt. Windu presented by no. 1 to 4 with dense vegetation covers as presented by NDVI value about 0.8.](image2)

The NDVI (Normalized Difference Vegetation Index) was applied to the Landsat 8 reflectance data
to calculate the vegetation cover quantitatively. This calculation was applied after atmospheric
correction process as explained later. The NDVI is an index of plant “greenness” or photosynthetic
activity. The green-less and unhealthy vegetation reflects more visible red light and less near infrared
(NIR). Contrary, the green and healthy vegetation absorb most visible red and reflect high portion of
near-infrared [5]. The NDVI is calculated by the following equation:

\[
NDVI = \frac{(NIR-Red)}{(NIR+Red)} = \frac{(Band 5-Band 4)}{(Band 5+Band 4)}
\]

(1)

Applied on reflectance values of each band mentioned

Brighter pixel in NDVI means high value related to healthy vegetation and darker pixel means lower
value related to unhealthy vegetation (Figure 2). The value range of NDVI is -1 to 1 where healthy
vegetation generally falls between values of 0.20 to 0.80 [6]. The range NDVI value in this study area
is -0.77 to 0.93 with average 0.72 (Figure 3). The average value shows that the study area has dense
vegetation environment. In particular, confirming the visual analyses, Mt. Malabar, Mt. Bedil, Mt. Wayang, and Mt. Windu were observed at dense vegetation area with NDVI value about 0.80.

\[ \text{Figure 3. Histogram of NDVI, the minimum, maximum, and mean values are -0.77, 0.93, and 0.72. The Skewness is located on right side of the data distribution, which is around the 0.20 – 0.80 threshold for healthy vegetation [6].} \]

3. Data
The satellite data used in this study are Landsat 8 data with acquisition time on September 10\(^{th}\) 2013 (Figure 1) and Hyperion data with acquisition time on June 25\(^{th}\) 2012 (Figure 4). There are 242 bands of Hyperion data in total, but 129 bands are not available. For producing reliable reference data, we excluded the uncalibrated bands and selected only 113 bands with high signal to noise ratio. The remote sensing data used in this study were provided by the http://earthexplorer.usgs.gov/.

Ten rock samples were collected at and around Mt. Malabar and identified as altered rocks by analyzing its spectra. Altered rocks are commonly identified with spectra absorption at 2.100 and 1.400 nm. The reflectance spectra of those samples were measured from visible to short-wave infrared regions (0.2 to 2.6 \(\mu\)m) using a SolidSpec-3700 spectrometer (Shimadzu) [1].

4. Methods
4.1. Atmospheric Correction
Remote sensing data on optical region carry the influence of some external factors, which may degrade the spectral features quality of ground objects. These factors are: (1) effects of the solar irradiance curve, and (2) atmosphere and topography. The effect of the solar irradiance curve arises from the fact that solar radiation intensity peaks at 0.48 \(\mu\)m and the radiation intensity drops off towards longer wavelengths, therefore the effects of solar irradiance is not uniform throughout the image. Atmospheric effects arise due to the fact that the image data are collected over a wide wavelength range, which includes atmospheric windows as well as atmospheric absorption and scattering. Topographic effects arise due to local landscape orientation [7].

In this study, The Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) module in ENVI 5.2 software was applied to Hyperion and Landsat 8 data. The FLAASH is a first-principles atmospheric correction modeling tool for retrieving spectral reflectance from hyperspectral and multispectral radiance images. FLAASH can accurately compensate for atmospheric effects, it corrects wavelengths in the visible through near-infrared and shortwave infrared regions, up to 2.5 \(\mu\)m [8]. The parameters used for the calculation were Tropical Atmospheric Model, 40 km for Initial Visibility, and Rural Aerosol Model.

4.2. Spectral Angle Mapper
The Spectral Angle Mapper (SAM) method was used to detect the occurrence of clay minerals spatially. The SAM determines the similarity between target spectra (t) and each of the reference spectra (r). This method treats both the unknown and reference spectra as vectors and calculates the spectral angle...
between them (Figure 5), a smaller angle means a closer match between those two spectra. The SAM is applied by the following equation [10]:

\[
\alpha = \cos^{-1} \left[ \frac{\tilde{t} \cdot \tilde{r}}{||\tilde{t}|| \cdot ||\tilde{r}||} \right]
\]

(2)

Figure 4. True Color Composite (TCC) of Hyperion reflectance data for RGB= Band 29, 20, 12. Locations of the measured field spectra were plotted in red plus symbol.

Figure 5. Illustration of Spectral Angle Mapper (SAM) method. A smaller spectral angle means a similarity between target (image) and reference spectra [9].

The SAM method was applied to both Hyperion and Landsat 8 data with ten references spectra obtained from field observation at ten altered material locations (Figure 6). Following ten input spectra from spectrometer measurements, the SAM method produced ten rule images from Hyperion and Landsat 8 data.

5. Result
Pixel spectra from both Hyperion and Landsat 8 reflectance data were compared visually. Generally, there was a reflectance increase from 400 to 800 nm, then decrease in wavelength longer than 800 to 2,400 nm. The reference spectra showed the same reflectance increase, in particular from 200 to 1,000 nm. Then decrease in wavelength longer than 1,000 to 2,600 nm. Some local maxima were found at 1,300, 1,500, 1,650, and 2,100 nm for Hyperion spectra.

Compared to reference spectra, reflected pattern at 1,300, 1,650, and 2,100 nm were found to be similar in Hyperion spectra. The absorption pattern at 1,200, 1,350, and 1,750 nm were found to be similar, either. Relatively, compared to reference spectra, Landsat 8 data only showed similarity between 400 to 800 nm. Thus, visual analysis showed that Hyperion spectra showed higher similarity to reference spectra than Landsat 8 (Figure 7).
Figure 6. Reference Spectra of SAM at ten observed locations, identified as altered materials as there was absorption at 1.400, 1.900, and 2.100 nm. The x-axis is the spectra wavelength ranging from 240-2.600 nm and y-axis is reflectance (%).

Figure 7. Spectra of Hyperion and Landsat 8 reflectance data (A) and measured spectra of alteration rock (B) at A1-2re in Figure 4. Generally, there was a reflectance increase from 400 to 800 nm, then decrease in wavelength longer than 800 nm. Some local maxima were found at 1.300, 1.500, 1.650, and 2.100 nm for Hyperion spectra (a, g, b, and c). Hyperion spectra showed higher similarity to reference spectra than Landsat 8 spectra, as shown by reflection (a, b, and c) and absorption (d, e, and f) pattern.

Quantitative analyses were conducted by pixel to pixel comparison between Hyperion and Landsat 8 SAM rule image. To compensate the spatial uncertainty, 3×3 pixels around the observed location were used for analyses. Therefore, each observed location was composed by nine pixels of rule image value.
to be compared. Pixel-1 is located at the top left, then pixel-9 at the bottom-right position (Error! Reference source not found.).

Lower rule image value means a high similarity of the reference to the target spectra, or high accuracy to detect target. Individually, most Hyperion SAM’s rule images at observed locations showed lower value compared to Landsat 8 SAM’s rule images, except for three pixels which were pixel-5 at location A17-1, and pixel-3 and pixel-6 at location WA1-12 (Table 2).

![Figure 8. Pixels value counting at SAM’s rule image for Hyperion data at location A1-2 re (red plus symbol). To compensate the spatial uncertainty, 3×3 pixels window (blue rectangle) were used. Each observed location had nine pixels for comparison purpose.](image)

| Location | A1-2 re | A1-9D | A17-1 | A17-3 | A4-1 | A4-9 | A5-10 | A5-5 | PA5-1 | WA1-12 |
|----------|---------|-------|-------|-------|------|------|-------|------|-------|--------|
|          | 0.47    | 0.45  | 0.67  | 0.59  | 0.51 | 0.60 | 0.70  | 0.49 | 0.46  | 0.38   |
|          | 0.45    | 0.52  | 0.62  | 0.55  | 0.53 | 0.60 | 0.71  | 0.49 | 0.46  | 0.22   |
|          | 0.47    | 0.56  | 0.55  | 0.48  | 0.54 | 0.60 | 0.72  | 0.48 | 0.45  | 0.24   |
|          | 0.45    | 0.46  | 0.66  | 0.60  | 0.49 | 0.57 | 0.68  | 0.50 | 0.46  | 0.43   |
|          | 0.44    | 0.45  | 0.62  | 0.53  | 0.49 | 0.57 | 0.70  | 0.49 | 0.46  | 0.30   |
|          | 0.48    | 0.51  | 0.57  | 0.43  | 0.50 | 0.57 | 0.70  | 0.48 | 0.46  | 0.36   |
| Hyperion |         |       |       |       |      |      |       |      |       |        |
|          | 0.48    | 0.45  | 0.65  | 0.58  | 0.44 | 0.56 | 0.69  | 0.50 | 0.46  | 0.53   |
|          | 0.47    | 0.43  | 0.65  | 0.53  | 0.43 | 0.56 | 0.71  | 0.49 | 0.47  | 0.47   |
|          | 0.50    | 0.50  | 0.65  | 0.46  | 0.44 | 0.57 | 0.71  | 0.48 | 0.46  | 0.51   |
|          | 0.77    | 0.55  | 0.84  | 0.70  | 0.58 | 0.74 | 0.84  | 0.71 | 0.66  | 0.76   |
|          | 0.70    | 0.62  | 0.84  | 0.59  | 0.55 | 0.74 | 0.85  | 0.72 | 0.65  | 0.71   |

Table 1. Pixels value of Hyperion and Landsat 8 SAM’s rule images at ten observed locations. Lower rule image value means a high similarity to spectra target. Most Hyperion SAM’s rule values showed lower than Landsat 8 SAM’s, except three pixels location in highlighted yellow.
Averaging was applied within pixels window for each location. This comparison showed that Hyperion SAM’s rule values at ten observed location were lower than Landsat 8. Obtaining the effectiveness of the two data, significant number \( (SN) \) was calculated and defined by the differential pixel means value \( (\Delta \bar{P}) \) and divided by Landsat 8 pixel means value. The calculation could be presented as follows:

\[
SN = \frac{\bar{P}_{\text{Landsat 8}} - \bar{P}_{\text{Hyperion}}}{\bar{P}_{\text{Landsat 8}}} \tag{3}
\]

The Hyperion SAM’s rule images showed better results for targeting altered rocks with its significant number ranging 15-31% and 24% average (Table 2). There are two craters among the sample locations, which are Burung Crater (A1-9D, A5-10 re) and Wayang Crater (WA1-12). The Lowest Hyperion SAM’s Rule images is located at WA1-12, agree with the Lowest on Landsat 8’s. This is relatively acceptable because of its lack vegetation cover as shown with NDVI value of 0.27. In general, higher NDVI value will result in higher rule images value. As a result, Hyperion data is 25% better than Landsat 8 at WA1-12.

The correlation between SN and NDVI value has not been clearly enough since SN at WA1-12 is both lower and higher compared to Burung Crater (A1-9D, A5-10 re) with high NDVI value ~1. Another result that certify the justification is that the lowest SN is located at A17-3 even its NDVI value showed relatively low (0.37).

Table 2. Pixel means value of Hyperion and Landsat 8 SAM’s rule images. Hyperion SAM’s rule images showed better results for targeting clay mineral with its average significant number 24%.

| Location | Hyperion | Landsat 8 | Significant Number | Description      | NDVI |
|----------|----------|----------|--------------------|------------------|------|
| A1-2 re  | 0.47     | 0.64     | 27%                | Altered Rock     | 0.67 |
| A1-9D    | 0.48     | 0.66     | 27%                | Burung-1 Crater  | 0.90 |
| A17-1    | 0.63     | 0.79     | 21%                | Altered Rock     | 0.69 |
| A17-3    | 0.53     | 0.65     | 19%                | Altered Rock     | 0.37 |
| A4-1     | 0.49     | 0.64     | 24%                | Altered Rock     | 0.68 |
| A4-9     | 0.58     | 0.76     | 24%                | Altered Andesite | 1.01 |
| A5-10 re | 0.70     | 0.83     | 15%                | Burung-2 Crater  | 1.02 |
| A9-5     | 0.49     | 0.71     | 31%                | Altered Andesite | 1.02 |
| PA5-1    | 0.46     | 0.64     | 28%                | Altered Rock     | 0.92 |
| WA1-12   | 0.38     | 0.51     | 25%                | Wayang Crater    | 0.27 |
| AVERAGE  | 0.52     | 0.68     | 24%                |                  |      |

6. Conclusions
Hyperspectral data showed better absorption similarity to the reference spectra than multispectral data. Hyperion with narrow spectral bands delivered the relative similar reflection and absorption pattern with the reference spectra. Based on pixels window comparison, most Hyperion SAM’s rule images showed lower values. The significant number using Hyperion was about 24% better than Landsat 8. This inferred
that the hyperspectral remote sensing is preferable for mineral mapping even though vegetation covered study area.

The Lowest Hyperion SAM’s Rule images is located at WA1-12, agree with the Lowest on Landsat 8’s. In general, higher NDVI value will result in higher rule images value. The correlation between SN and NDVI value has not been clearly enough since SN at WA1-12 is both lower and higher compared to Burung Crater (A1-9D, A5-10 re). Another result that certify the justification is that the lowest SN is located at A17-3 even its NDVI value showed relatively low.

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