GENERAL ARTICLES

Landsat 8 OLI data for identification of hydrothermal alteration zone in Singhbhum Shear Zone using successive band depth difference technique – a new image processing approach

Krishnendu Banerjee, Manish Kumar Jain, A. T. Jeyaseelan and Surajit Panda

Recent advances in calculation algorithms have led to a new level of image processing for mineral identification and mapping. Mineral outcrop mapping has a decade’s history of using conventional methods like band combination, band ratioing and relative absorption band depth (RBD) technique. Modification of these algorithms enriches the capabilities of object identification and mapping. Band combination and band ratioing help to locate the distribution of a hydrothermal altered zone. In the current study, an attempt has been made to modify the RBD approach. Newly introduced successive band depth difference (SBDD) measures the difference of reflectance values in successive bands by dividing the sum of the two highest successive shoulders by the shoulder of the lowest value before the starting shoulder. Band math function has been used in various bands of Landsat 8 operational land imager (OLI) data to access the precise distribution of points of the hydrothermal altered zone. SBDD method has achieved a kappa coefficient of 0.86 which depicts significant levels of accuracy.

Keywords: Relative absorption band depth, RGB, signal-to-noise ratio, SBDD, TIRS.

ADVANCEMENT in spectral remote sensing technologies has improved significantly over the past two decades, with the use of multispectral remote sensing data, particularly for hydrothermal mineral mapping system1. The remote sensing mineral investigation technique depends on surface composition and its absorption of energy. Various techniques process multispectral imagery to acquire surface compositional character and information on a pixel to pixel basis for the entire image2.

The commonly used algorithms include the spectral angle mapper (SAM)3, spectral feature fitting (SFF)4, principle component analysis (PCA), spectral binary encoding (SBE)5, mixture tuned matched filtering (MTMF)6, spectral absorption index (SAI)7, absorption band-depth8 and RBD analyses9–11.

Crowley et al.9 used radiance data to develop the RBD method for mineral mapping. A three-point band ratio formulation technique was also known as RBD10. The RBD image was produced by adding and then dividing the ‘absorption-band shoulders’ by adjustment bands of the same channel series respectively (RBD = (band 1 + band 2)/band 3). Therefore, RBD images offer the depth of an absorption feature relative to ‘local continuum correction’12.

This study uses modified RBD or newly introduced SBDD approach for mineral prospectivity mapping. The SBDD approach calculates the depth difference between two successive peak channels. Hence, all available Landsat 8 Operational Land Imager (OLI) bands have been analysed and integrated using these ‘modification of RBD’ or ‘SBDD’ methods for porphyry copper mineral prospectivity mapping in Singhbhum Shear Zone (SSZ)11.

Landsat 8 OLI data processing

Data-driven techniques are used for preliminary identification of hydrothermal alteration mineral zones through different colour compositions. Band ratio helps to highlight the target areas. Successive band depth difference approach and logical operators are implemented to extract
Table 1. Band specifications of ASTER and Landsat 8 sensors

<table>
<thead>
<tr>
<th>Sensors</th>
<th>Subsystem</th>
<th>Band number</th>
<th>Spectral range (μm)</th>
<th>Spatial resolution (m)</th>
<th>Swath width (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>0.433–0.453</td>
<td>185</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>0.450–0.515</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VNIR</td>
<td>3</td>
<td>0.525–0.600</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.630–0.680</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.845–0.885</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landsat 8 OLI and TIRS</td>
<td>SWIR</td>
<td>6</td>
<td>1.560–1.660</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2.100–2.300</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 (Pan)</td>
<td>0.500–0.680</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cirrus</td>
<td>9</td>
<td>1.360–1.390</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIRS</td>
<td>10</td>
<td>10.60–11.20</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>11.5–12.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: ASTER user handbook and Landsat 8 (L8) data user handbook.

Figure 1. Location and geology of the study area.

Figure 1. Location and geology of the study area.

the alteration zones. Landsat 8 OLI has been used to identify clay minerals which are characterized by absorptions features in shortwave infrared channels. Landsat 8 covers visual to shortwave infrared spectrum channel in nine consecutive bands covering a 185 km swath. Eight bands have 30 m spatial resolution except for a 15 m panchromatic band as shown in Table 1 (ref. 14). Landsat 8 OLI has the greater 12-bit quantization which makes it more preferable for mineral mapping.

Geological history of the study area

The study area is located at Singhbhum Copper Belt of Jharkhand which is one of the mineral-bearing stretches of India with high potential (Figure 1). The arcuate belt stretches for over 200 km between Baharagora in the south-east and Duarpuram in the west. Physiographically, the area consists of ridge systems underlined by characteristic rock types such as the Dalma lava and its variants, quartzites, quartzose phyllites, etc. The area is developed on (i) Singhbhum granite in the southwest, (ii) schists on either side of the Subarnarekha valley and (iii) raised tracts of red soil which may be underlain by tertiary gravels.

Major stratigraphic units of ‘Copper Belt Thrust’ suggested by Dunn, can be separated by Iron Ore Group (including the ‘Gorumahisani Group’) on the south and the Singhbhum Group on the north. The major copper mineral is chalcopyrite which occurs in veins and patches associated with chlorite schist. Quartzites and granites are the siliceous rocks found in mylonitized equivalents. These types of rocks are characterized by soda rich feldspars. The sulphides of the shear zone are mainly associated with chalcopyrite, pyrite, pyrrhotite and magnesite. Chlorite and sericite quartz and biotites are found in multiple forms.

Preprocessing of data

Landsat 8 image (LC81390442016317LGN00, path/row 139/44) was downloaded from the United States Geological Survey (USGS) website. This Landsat 8 OLI data was captured on 12 November 2016, which covers the entire East Singhbhum district along with the study area. The satellite image information is provided in Table 2. Pre- and post-processing of Landsat 8 OLI satellite data was carried out using environment for visualizing images (ENVI) version 4.8 software (Figure 2). Fast Line-of-Sight Atmospheric Analysis of Hypercubes (FLAASH) atmospheric correction module was used for atmospheric correction. All the bands of Landsat 8 data were layer stacked and the central wavelength value was assigned to each band for further analysis.
Image processing

Band combinations

True colour images are the composite result of three visual primary grey images. Colour images are composed of three primary colours, i.e. blue, green and red. False colour images, mainly colour infrared images, have specific advantages over true colour. While it is easy to recognize different geological units using true colour images colour infrared images also present geology quite well\(^2\). Band combinations eliminate most atmospheric attenuation like haze, back scattering, etc. Different combinations of false colour band scan highlight many features ranging from mineralogical changes to moisture changes, etc.\(^2\). The main advantage of true colour images is that it is easy to recognize units in areas where the stratigraphy is known and increase the ability of the interpreter in the identification of rock units where the geologic section is unknown\(^2\). Historical studies are the evidence of Landsat 8 OLI image capabilities, which utilize some set of band numbers for rock discrimination of alteration zones based on colour intensity variations, such as RGB of B7, B6, B4 or RGB of B5, B6, B7 (Figures 3 and 4)\(^3\). However

<table>
<thead>
<tr>
<th>Table 2. Landsat 8 OLI image metadata information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scene center time: 04:37:30.6183250</td>
</tr>
<tr>
<td>Cloud cover: 2.98%</td>
</tr>
<tr>
<td>Sun azimuth: 153.52916597</td>
</tr>
<tr>
<td>Sun elevation: 44.92756117</td>
</tr>
<tr>
<td>Pixel size 9 (m): 30</td>
</tr>
<tr>
<td>Earth sun distance: 0.9897199</td>
</tr>
<tr>
<td>Map projection: UTM</td>
</tr>
<tr>
<td>Datum: WGS84</td>
</tr>
<tr>
<td>UTM zone: 45</td>
</tr>
</tbody>
</table>


Figure 2. Methodology flow chart of Landsat 8 data analysis.

Figure 3. RGB colour combination of bands 5, 6 and 7 of Landsat 8 satellite image.

Figure 4. RGB colour combination of bands 7, 6 and 4 of Landsat 8 satellite image.
extracting band combinations that illuminate the target litho-units are quite difficult.29

**Band ratio**

Band ratio can reduce the effect of environmental artefacts. Previous studies illustrated typical band ratios which have been used for enhancing lithological features.1,13,14

Most effective band ratio practices used by Sabins’ for geological mapping, are RGB of 4/2, 6/7 and 6/5 (Figure 5a). Sabins’ band ratio is beneficial for lithological mapping and detection of hydrothermal alteration zones.1,30

Previous studies suggest that iron-rich minerals or other minerals associated with hydrothermal processes can be delineated using 4/2 of Landsat 8 OLI image.12

Band ratio of Landsat 8 OLI image 6/7 is beneficial for mapping clay minerals like kaolinite, illite and montmorillonite.31

Ali and Pour30 suggest a combination of Landsat 8 OLI image 4/2, 6/7 and 5 as RGB for identification of lithology, altered rocks, and vegetation. Kaufmann band ratio (7/5, 5/4 and 6/7) was also used for separation of vegetation from altered zones.30

Band ratios derived from images 4/2, 6/7, 5 and 4/2, 6/7, 10 as RGB depict separability of rock units and alteration zones precisely (Figure 5c and d).32 Colour variations can be seen in different band ratio results which are the primary keys to identify a hydrothermally altered zone.

Several pair of bands have offered delineation of various rock-mineral types such as: (a) 4/2 – iron oxide, (b) 6/7 – hydroxyl bearing rock, (c) 7/5 – clay minerals and (d) 6/5 – ferrous mineral.32,33
Relative absorption band depth method

Band ratio, PCA and RBD are some common methods to detect hydrothermally altered zones. Band ratio suppresses the common attribute in two bands. Band ratio images are designed to highlight the spectral contrast of specific objects having absorption characteristics in the entire channel\(^3\),\(^4\). Band ratio (BR) divides one band by another to create a new image that may be used to highlight a particular type of feature\(^5\),\(^6\). RBD divides the sum of two highest reflectance spectral bands which may be in a sequence in the spectral channel or not, by the lowest absorption spectral channel (Figures 6 and 7).\(^7\). RBD images are the result of a three-point ratio formulation for displaying Al–O–H, Mg–OH and CaCO\(_3\) absorption strengths\(^8\),\(^9\).

RBD reduces radiometric miscalibrations which can misguide the interpreter. RBD produces a local continuum correction (LCC) which removes any small channel-to-channel radiometric offsets. RBD provides information on solar irradiance drop-off for each pixel in the dataset and irregular atmospheric absorption\(^8\),\(^9\),\(^10\). Absorption features associated with local continuum detect pixels having greater absorption bands, which indicates presence of a particular mineral\(^9\).

Successive band depth difference technique

In the present study, an attempt was made to modify the RBD approach. SBDD measures the difference in reflectance value of successive bands by dividing the sum of two highest successive shoulder channels by the bottom channel before the starting shoulder (Figure 8). Both RBD and SBDD image processing methods are used to identify lithological units as well as hydrothermally altered zones. Depth difference of two highest reflectance channels can be calculated by this method. Landsat 8 OLI data have absorption features in different band numbers which were used to analyse a specific mineral type. Chlorite and epidote have extensive Fe\(^{2+}\)\(^\text{absorption feature in the 0.66–1.65 \, \mu m region\(^3\),\(^4\). Alunite and kaolinite have Al–O–H absorption features at 2.17 \, \mu m and 2.20 \, \mu m respectively. Muscovite has a prominent Al–O–H 2.20 \, \mu m absorption feature and a secondary 2.35 \, \mu m absorption feature\(^3\),\(^4\).

Data analysis

Crowley et al.\(^9\) have developed a method of RBD which was processed through radiance data. In the present study radiance data of Landsat 8 OLI was used for the image analysis and identification of hydrothermally altered zones. Layer stacking and subsetting the image of the study area was carried out. Colour variation in different band combination and ratio images confirmed the location of the hydrothermally altered zones. Depth-based image analysis of spectra needs precise pixel locations. Geological
Survey of India (GSI) location points of copper have been superimposed in RGB with 5, 6, 7 bands of Landsat 8 OLI data to perceive spectral characteristics of ore outcrops for further analysis (Figure 9). Hydrothermally altered mineral shows absorption feature (0.66 μm) in a known sample location (Figure 10)\textsuperscript{31,41,42}. RBD approach suggests dividing the sum of two peak reflected shoulders by the lowest absorption channel between them. Local continuum removal is possible by this approach. SBDD approach calculates the depth difference between two successive peak channels (Figure 10).

Typical spectral curve (Figure 10) depicts the conceptual parameters used in the SBDD calculation. Infrared to shortwave region of the electromagnetic spectrum is most significant to iron oxides, oxyhydroxides, and clay minerals which are formed by high or low-temperature alteration\textsuperscript{43,44}. A significant level of band absorption can be noticed in SWIR channels (1.5 and 2.3 μm)\textsuperscript{45}. Molecular vibrations from species such as hydroxyl, water, carbonate and sulphate are the sign of transition metals (generally iron or copper)\textsuperscript{46,47}. Electronic orbital configuration and the combined overtones of molecular vibration process are responsible for such band absorption effects in transition metals\textsuperscript{30}. Three successive bands of Landsat 8 OLI data, B5 (NIR), B6 (SWIR1) and B7 (SWIR2) have been used for the calculation. The integer and float value images...
Table 3. Accuracy assessment statistics of different mapping procedures used in multispectral image

<table>
<thead>
<tr>
<th>Satellite image</th>
<th>User accuracy (%)</th>
<th>Producer accuracy (%)</th>
<th>Overall classification accuracy (%)</th>
<th>Overall kappa statistics (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band combination</td>
<td>80.00</td>
<td>70.59</td>
<td>84.62</td>
<td>0.6395</td>
</tr>
<tr>
<td>Band ratio</td>
<td>73.33</td>
<td>78.57</td>
<td>86.79</td>
<td>0.6679</td>
</tr>
<tr>
<td>SBDD</td>
<td>93.33</td>
<td>87.50</td>
<td>94.34</td>
<td>0.8633</td>
</tr>
</tbody>
</table>

Figure 11. Sample collection and GPS surveying of study area.

of SBDD technique were processed through ENVI software’s band math function using simple logical expressions. Equations are given below. SBDD of float value image was calculated using eq. (1).

\[(\text{float (b1)} + \text{float (b2)})/\text{float (b3)}\]. \hspace{1cm} (1)

The integer value of the same was calculated using eq. (2).

\[(\text{b1} + \text{b2})/\text{b3}\]. \hspace{1cm} (2)

The integer and float value images were calculated for elimination of mixed pixel values which were non-targeted materials or non-hydrothermally altered zones. Such data values were eliminated through interactive data language (IDL) and logical operators. A critical threshold value of 2.10 was assigned in the operation (eq. (3)). The threshold value was decided after examining known points of chalcopyrite occurrence. The integer value image shows three data types 0, 1 and 2. The integer value image was compared with the float value image. ENVI software uses a typical type of conversion factor while processing the band math function for float value image. This conversion factor of ENVI facilitates the extraction of floating point difference up to 0.10 interval. The mathematical expression in eq. (3) does the same. The first operation in eq. (3) eliminates float values above 2.10 and the second operation extracts the value of 2.00. Both operations are connected through a logical ‘and’ operator which fetches the demanded values when both the expressions are satisfied simultaneously (eq. (3)). The value image of (2.10–2.00) = 0.10 difference can be extracted by the above procedure. The output value image provides the output in true and false value point in which true values are presented as 1 and false values are presented as 0 (Figure 9a and c).

\[((\text{b1 le 2.10}) \text{ and } (\text{b2 eq 2}))\]. \hspace{1cm} (3)

Results and discussion

Dark blue patches in the north-western and south corner of the study area confirm the presence of hydrothermal alteration zones (RGB 5, 6, 7; Figure 3). The second RGB (7, 6, 4) shows dark brown colour in the same areas
(Figure 4). Sabins’ ratio (4/2, 6/7 and 6/5 as RGB) helps to recognize the hydrothermally altered zones in violet colour which can be seen in the North, South and North Eastern portions (Figure 5 b). Band combination of 4/2, 6/7 and 5; 4/2, 6/7 and 10 was suggested by Hasim et al.48. The result of these band ratios represents the tonal difference in vegetation, water and hydrothermally altered zones. Light and dark violet colour in RGB of 4/2, 6/7, 10 (Figure 5 c) and 4/2, 6/7, 5 (Figure 5 d) confirm the presence of hydrothermally altered minerals in the southern and northern part of the study area (Figure 9 d). Overall accuracy of band combination, band ratio and SBDD was compared. The accuracy assessment was carried out using GPS location and GSI mineral locations. Band combination and band ratio methods show 0.63 and 0.66 of kappa statistics. SBDD based porphyry copper zonation map shows 94.34% of overall classification accuracy and kappa coefficient of 0.86 (Table 3). Field verification and data collection was carried out using hand-held GPS and digital camera. Geo-tagged field photos were collected in mining areas and their surroundings (Figure 11).

Conclusion

Band combination, band ratioing and RBD approach are conventional methods used for explicit mineral identification in large scale. Field surveying methods for mineral outcrop mapping are difficult and time consuming. Different band combination and ratio images represent various colours of rock minerals and are key to mineral identification. SBDD method is a spectral depth-based method which needs prior knowledge of the targeted mineral spectra. Misinterpretation of target spectra may lead to wrong SBDD calculation. SBDD method uses radiance data of satellite image which is biased by atmospheric attenuation such as gases, dust particles, haze, etc. and hence can reduce overall accuracy.

16. Geological Quadrangle Map (Jamshedpur Quadrangle, Bihar, Orissa and West Bengal) of Geological Survey of India.