Spectral mineral mapping for characterization of subtle geothermal prospects using ASTER data

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Abstract. In this study, the performance of ASTER data is evaluated for mapping subtle geothermal prospects in an unexplored tropical region having a number of thermal springs. The study employed a simple Decorrelation stretch with specific absorptions to highlight possible alteration zones of interest related to Geothermal (GT) systems. Hydrothermal alteration minerals are subsequently mapped using Spectral Angle Mapper (SAM) and Linear Spectral Unmixing (LSU) algorithms to target representative minerals such as clays, carbonates and Al-OH minerals as indicators of GT activity. The results were validated through field GPS survey, rock sampling and laboratory analysis using latest smart lab X-Ray Diffractometer technology. The study indicates that ASTER broadband satellite data could be used to map subtle GT prospects with the aid of an in-situ verification. However, it also shows that ASTER could not discriminate within specie minerals especially for clays using SWIR bands. Subsequent studies are aimed at looking at both ASTER and Hyperion hyperspectral data in the same area as this could have significant implications for GT resource detection in unmapped aseismic and inaccessible tropical regions using available spaceborne data.

1. Introduction

Globally, there is a serious energy concern and the clamour for sustainable alternative energy sources to forestall global warming and other unforeseen extreme climatic conditions. Geothermal (GT) resources, which are heat sources from the crust that can be harnessed for various uses, offers a reliable and sustainable alternative renewable energy not only in terms of power but other uses requiring less heat from the ground [1]. GT systems are associated with magmatic intrusions, which could serve as the source of heat. However, some GT systems are amagmatic and may occur in regions characterized by meteoric water rise within permeable crusts. In such regions hot fluids ascend to the surface as hot springs, geysers and fumaroles [1]. GT systems may sometimes not have obvious surface manifestations but rather, subtle expressions such as hydrothermally altered rocks and minerals including clays, carbonates, silicates and calcites. These minerals are by-products of alteration as a result of metasomatism [2]. Blind and fossilized GT systems are characterized by these subtle imprints which are not easily identifiable using conventional techniques [2]. Remote sensing and spectroscopy offers a unique tool for synoptic detection of such prospective GT sites and have been successfully used in the prefeasibility stages of exploration by the detection of associated minerals as proxy [3]. However, previous studies have been focused in volcano-tectonic regions; there has been limited studies in unconventional aseismic settings with characteristically subtle GT features. There is the need for more studies in such regions and their identification using state of the art techniques of remote sensing and spectroscopy. This is especially true with the promising advances
expected in the enhanced geothermal systems (EGS) which could make many regions of the world exploitable for GT renewable energy [1].

In this study, we assessed the applicability of the ASTER SWIR bands in discriminating subtle hydrothermal mineral signatures associated with GT systems as proxy for indirect characterization of hidden or fossilized systems, which are difficult to discern using only conventional survey techniques. The Wikki and Mawulgo thermal springs in Yankari Park area are studied.

2. Materials and Methods

2.1 Geology of the study area

The Yankari Park is located within Latitude 9.7500°N, and Longitude 10. 5000°E in Bauchi State, northeastern Nigeria (Fig. 1). Territorially it extends to about 2,244 square kilometres (866 sq. mi) [4]. Thermal springs in the Park include; Dimmil, Gwana, Mawulgo and Wikki. Geologically, it is within the Kerri formation characterized by Neogene to Mesozoic older sedimentary rocks which is composed of sandstone, silt stones, kaolinites, grits and clays [5]. It is also part of the Benue Trough, bordered to the west by the basement complex crystalline rocks of the Jos plateau, to the northeast by the Biu plateau and to the southeast by the Adamawa highlands. Figure 1 shows geological map of Nigeria with Yankari Park.

2.2 ASTER remote sensing data

ASTER level 1T (AST_L1T, path/raw, 187/53) scenes with 25th January 2006 acquisition date covering the Yankari Park study area were obtained from the LPDAAC data pool. The ASTER level 1T is a Precision Terrain Corrected Registered At-Sensor Radiance that has been geometrically rectified, and turned to a north-up Universal Transverse Mercator (UTM) 32N projection with WGS 84 Datum. The data was atmospherically corrected using the internal average relative reflection (IARR) algorithm [6]. The image is thus converted from radiance to apparent reflectance to facilitate subsequent spectral analysis.

2.3 Data processing

A spatial subset was made of the ASTER scene focusing on Field surveyed areas around the Wikki and Mawulgo thermal springs and their proximate areas (Fig. 2). A decorrelation stretch (DCS) is first applied to the ASTER data to identify possible alteration areas of interest, this was done carefully with the specific minerals of interest in mind [6]. This included argillic alteration minerals including clays, carbonates, sulfates which are known to have diagnostic absorption features in the SWIR around (2.0 to 2.4 um), while limonitic alterations as a result of iron oxides and hydroxides show characteristic features within the VNIR around (0.3-1.6um) [7]. The focus of the study is to identify hydrothermal alteration zones associated with these minerals proximate to GT systems. In subsequent analysis, Spectral Angle Mapper (SAM) and Linear Spectral Unmixing (LSU) techniques are employed to target these alteration indicators and their pixel abundance on the ASTER data. The results are discussed below.
3. Results and discussion

3.1 Decorrelation Stretch (DCS)

The DCS is an image enhancement technique capable of highlighting image elements that are nearly invisible in true colour images by increasing the visualization of features [3] such as hydrothermal alteration zones of interest. It is employed in this study to visually heighten the spectral variations by removing the correlation among three input bands [8]. Figure 2 highlights red areas as possible argillic alteration zones, green as advanced argillic and blue as areas of carbonates [9]. The bands for DCS were carefully selected based on the absorption features of targeted alterations of interest.

Figure 1. Geological Map of Nigeria showing Yankari Park location, modified from [5]

Figure 2. DCS bands 6, 5 and 8 in RGB and sampling site at M5 Mawulgo thermal spring
Many hydrothermal alteration minerals show diagnostic reflectance characteristics in the SWIR region. For instance, clay minerals show absorption within 2.20 µm due to vibrational transition of hydroxyl ions and their bonding with Al-OH or Mg-OH cations while carbonates manifest within 2.35µm [7]. Thus, the DCS was done using ASTER bands 6 (2.209µm), band 5 (2.167) and band 8 (2.336). The DCS bands 6,5 and 8 were loaded as RGB. However, it is observed that the faint pink tones of the argillic alteration zones signifies weak alteration thus suggesting the need for more detailed analysis [6]. Subsequently analysis is focused on M5 around Mawulgo where samples were obtained in the field and observed during field sampling to have clay alterations (Fig. 2).

3.2 Spectral Angle Mapper (SAM) Classification
SAM is a whole-pixel classification method used for comparing image spectra (an unknown) to a known reference spectra e.g. from spectral libraries, ASCII files etc. [3]. In this study, the reference spectra is chosen from USGS spectral library. The SAM techniques estimates the similarity between the image spectrum and the reference spectrum by calculating the angle between the two spectra while treating them as vectors in n-dimensional space [6]. To identify the argillic alteration zones that are indicated by the presence of clay minerals, five endmembers were selected from the spectral library (Fig. 3a). These included Kaolinite 1 and 2, Illite, Montmorillonite and Muscovite. A spectral subset of only SWIR bands was made and the selected endmembers are used as reference spectra with class colours as plotted in the Endmember collection spectra in Figure 3. Maximum radian angle of 0.100 was used. The result of the SAM is shown in Figure 3(b) that depicts Kaolinite as (red) pixels, Montmorillonite as (blue), and most of the pixels are classified as Illite and no pixel was classified as muscovite. The result indicates that the ASTER SWIR band could not discriminate within specific minerals since Kaolinite 1 and 2 were used in the analysis but only Kaolinite 1 is discriminated. The result however, identifies altered minerals of argillic alteration, which are of GT importance.

Figure 3. (a) Endmember collection spectra used as reference (USGS library spectra) for the analysis and (b) SAM rule image of M5 Mawulgo area showing SAM results for endmembers used as library spectra

3.3 Linear Spectral Unmixing (LSU)
The LSU algorithm is used to determine the actual proportion or abundance of pure endmember (class) materials within a pixel. The energy recorded by a remote sensing detector is a function of the amount of energy reflected or emitted by the materials within the Instantaneous Field Of View [7]. ENVI 5.1 was used to determine the distribution and relative abundance of the five indicator minerals as endmembers in the ASTER subset image. The LSU relies on the assumption that the reflectance at each pixel of the ASTER image is a linear combination of the reflectance of each endmember present within the pixel [9].
The result of LSU is depicted in Figure 4a, the image shows pixel abundance of Illite as cyan similar to the results in SAM, Kaolinite as red and Montmorillonite as blue. The sub-pixel LSU however, classified some areas initially of kaolinite in SAM, as Muscovite in (pink). It was observed that fewer pixels are classified as Kaolinite area at M5 which also corresponds to sampling sites where XRD results indicated presence of kaolinite and Quartz (see Figure 4b). It was however, observed that when Kaolinite 1 and 2 are loaded together with Montmorillonite as RGB, the LSU also classifies areas of Illite as Kaolinite indicating that the broad bands of ASTER is not effective in discriminating clay minerals with very close absorption features [10]. This signifies the need for using ASTER together with a sensor with higher spectral fidelity such as hyperspectral in detecting subtle GT related hydrothermal alteration minerals.

Figure 4. (a) LSU image map showing relative abundances of 4 endmembers Illite, Kaolinite, Muscovite and Montmorillonite on grayscale image at M5 and (b) X-Ray Diffraction results showing Quartz, Kaolinite mineral from altered rock samples at M5

The root mean square error (RMSE) image in Figure 6 shows the uncertainties in the mixing calculations and how well the least square solution was able to match the spectra [10]. This is indicated by bright pixels which show high values and high errors while the dark pixels indicate low errors and good fit [10, 11, 12]. The results of the RMSE (0.495) image indicates that areas around M5 where sampling was made was also classified sufficiently as shown by the dark pixels in the image area by the LSU algorithm which indicates the abundance of illite and Kaolinite with fewer pixels classified as montmorillonite and muscovite. The LSU thus better discriminates the alteration zones as compared to the SAM technique.

Figure 5. Root mean square error (RMSE) image showing bright as high error and dark as low error pixels in the LSU classification
4. Conclusion
This investigation shows the applicability of ASTER in discriminating subtle GT indicator minerals as proxy for identifying prospects and by narrowing targets for comprehensive surveys especially when backed with simple field validation. Alterations were identifiable around non-vegetated exposed areas at M5. However, despite ASTER SWIR ability to discriminate within specie alteration minerals, it is robust in identifying argillic and Hydroxyl-bearing alterations in general, which are very significant in identification of subtle GT surface mineralogical imprints. This could have implications for exploration of GT resources in unmapped regions characterized by subtle features with promising potentials.

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