The Application of Remote Sensing Techniques for Identification the Gypsum Rocks in the Qara Darbandi Anticline, Kurdistan Region of Iraq

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Abstract

The application of remote sensing techniques in geological investigation are used to determine the prospected area of gypsum rocks in the Qara Darbandi Anticline, Kurdistan Region of Iraq. This study aimed to assess the effectiveness of Spectral Angle Mapper (SAM) supervised classification in mapping gypsum rocks applying Landsat Imagery. Rapid-Eye and Landsat multispectral satellite images are used. Image enhancement techniques such as Minimum Noise Fraction (PCA) and Principal Component Analysis (PCA) were employed to perform image transformation methods. The spectral data was collected using an Analytical Spectral Devices (ASD) field spectrometer, and the spectra of gypsum rocks were utilized as the training area zone for the classification of SAM. SAM output map displays the best indication of the gypsum rocks distribution in the southwestern part of Qara Darbandi anticline. Results showed that the FCC (R:3; G:4; B:1); MNF (R:1; G:2; B:3 and R:4; G:3; B:2) and PCA (R:3, G:1, B:2) are the best compositions to determine the outcrop of the Gypsum rocks within the selected area. These findings show the capability of spectral bands of the Rapid-Eye sensors, and Landsat imagery, in addition to the capability of the image processing methods to detect and map the exposed Gypsum rocks. In conclusion, the findings of this study are supported by the fieldwork conducted, the analysis of geochemistry data, and the examination of available geological maps.

Keywords: Image transformation; SAM classification; Gypsum Rocks; Mapping; geochemistry

1. Introduction

Gypsum rocks are chemical sedimentary rock form in a wide and shallow foreland basin located near the Zagros and Taurus mountains. These rocks are primarily evaporitic in nature and are composed of multiple cycles of Murdock's, limestone, gypsum, and anhydrite, which exhibit a shallowing-upward pattern (Al-Juboury and McCann, 2008; Jassim and Goff, 2006).

Gypsum rocks are widely distributed in northern Iraq, primarily within the Middle Miocene, Fatha Formation (Lower Fars) (Jassim and Goff, 2006; Al-Juboury and McCann, 2008). Gypsum rock is one of the significant industrial rocks, such as in the plaster manufacturing, wall panels, tiles, cement, and ceramics. Gypsum rocks are exposed in the form of layers and may appear in the form of large domes (Tucker, 2003; Yilmaz et al., 2011).
Remote sensing plays a significant role in geology, particularly in the identification of crucial structures, mapping of rock units, and exploration of natural resources. However, the utilization of satellite images holds immense potential in surveying natural resources, including assessing vegetation coverage, identifying various rock types, and detecting mineral deposits (Rowan and Mars, 2003; Zhang and Pazner, 2007; Gabr et al., 2010; Mars and Rowan, 2010; Amin et al., 2011; Amer et al., 2012; Pour et al., 2013; Rajendran and Nasir, 2014; Khan et al., 2020). The utilization of GIS and remote sensing technologies is crucial in the process of updating geological maps and offers a viable approach to generating geological maps using satellite imagery (Othman and Gloaguen, 2014).

Traditionally, the process of identifying rock units and conducting geological exploration has been laborious, expensive, and time-consuming, heavily reliant on extensive fieldwork (Ramakrishnan and Bharti, 2015). Remote sensing serves as a consistent resource for geological mapping, taking into consideration certain factors that need to be considered when mapping the rock structure’s distribution such as clouds, vegetation, and atmospheric effects. Several scholars have effectively employed ASTER data to systematically map gypsum reserves in various countries including Turkey, Spain, Oman, Iraq, and Iran (Crosta and Moore, 1989; Thannoun and Al-Alaf, 2005; Kavak, 2005; Daoood, 2009; Serkan Öztan and Lütfi Süzen, 2011; Salati et al., 2014; Thannoun et al., 2018; Rajendran and Nasir, 2021).

The aim of this study was to identify and map the locations of the gypsum rocks in the Qara Darbandi Anticline, Sulaimani Governorate, by applying remote sensing techniques.

1.1. Geographic Location and Geological Setting of the Study Area

The study area is situated in the northern region of Iraq, specifically within the administrative boundaries of the Kirkuk Governorate. Encompassing an approximate area of (7200 km²), it is geographically positioned between latitude coordinates 36°24'0.0"N and 36°2'30.0"N, and longitude coordinates 44°24'0.0"E and 43°29'0.0"E. From a geological perspective, the mountainous terrain in the study area exhibits distinctive features such as asymmetrical, cylindrical, and elongated folds. Numerous structural elements are exposed on the surface throughout this region. Notably, the Kirkuk, Bai-Hasan, and Qarachuq anticlines represent prominent structural elements, with their fold axes oriented in a northwest-southeast direction. The oldest rocks exposed in this area belong to the Kirkuk formations group, which dates back to the Oligocene period (Fig. 1, Table 1). Recently, the utilization of GIS and remote sensing technologies are crucial in the process of updating geological maps and offers a viable approach to generate geological maps using satellite imagery. Remote sensing serves as a consistent resource for geological mapping, taking into consideration certain factors that need to be considered when mapping the distribution of rock structures. These factors include the presence of clouds, vegetation, and atmospheric effects, which can potentially impact the sensor records of surface reflectivity.

Remote sensing plays a significant role in geology, particularly in the identification of crucial structures, mapping of rock units, and exploration of natural resources (Othman and Gloaguen, 2014). Traditionally, the process of identifying rock units and conducting geological exploration has been laborious, expensive, and time-consuming, heavily reliant on extensive fieldwork (Ramakrishnan and Bharti, 2015). However, the utilization of satellite images holds immense potential in surveying natural resources, including assessing vegetation coverage, identifying various rock types, and detecting mineral deposits (Amer et al., 2012; Gabr et al., 2010; Khan et al., 2020; Mars and Rowan, 2010; Amin, Mazlan and Maged, 2011; Pour et al., 2013; (Rajendran and Nasir, 2014; Rowan and Mars, 2003; Zhang and Pazner, 2007).
Fig. 1. Geological Setting and Location of the study area (a) the geographical location and (b) the tectonic setting.

Table 1. The geochronological exposure of the geological formations (Sissakian and Fouad, 1993).

<table>
<thead>
<tr>
<th>Formation</th>
<th>Rock description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilaspi</td>
<td>well bedded, white and grey limestone and chalky marl with chert nodules.</td>
</tr>
<tr>
<td>Fatha</td>
<td>green marl, limestone, and gypsum at the lower member of the formation and</td>
</tr>
<tr>
<td></td>
<td>red claystone, marl, limestone, gypsum, and siltstone at the upper member.</td>
</tr>
<tr>
<td>Injana</td>
<td>sandstone, siltstone, and claystone.</td>
</tr>
<tr>
<td>Mukdadiy</td>
<td>Pebblly sandstone siltstone and claystone.</td>
</tr>
<tr>
<td>Bai Hassan</td>
<td>conglomerate in addition to the previous components.</td>
</tr>
</tbody>
</table>

Several scholars have effectively employed ASTER data to systematically map gypsum reserves in various countries including Turkey, Spain, Oman, Iraq, and Iran (Crosta and Moore, 1989; Thannoun and Al-Alaf, 2005; Kavak, 2005); Serkan Öztan and Lütfi Süzen, 2011; A Daood, 2009; Thannounet al., 2018; Salati et al., 2014; Rajendran and Nasir, 2021). Because of the economic importance of gypsum rocks and their multiple uses, this study aimed to identify and map the locations of these rocks by adopting applications of remote sensing within the study area. In this article, the application of Rapid-Eye satellite image data and ASD Field spectroradiometer (Analytical Spectral Devices) has been employed to identify and conduct comprehensive mapping of the gypsum outcrop in the specified area, such as Qara Darbandi Anticline, Sulaimani Governorate, Kurdistan region, NE-Iraq. The data obtained from the digital processing of satellite images was confirmed through intensive fieldwork and available access to the geological maps.
2. Materials and Methods

The application of Rapid-Eye satellite image data and a spectro-radiometer (ASD) are employed to identify and conduct comprehensive mapping of the gypsum outcrop in the specified area, Qara Darbandi Anticline, Sulaimani Governorate, Kurdistan Region, NE-Iraq. The data obtained from digital processing of satellite images was confirmed through intensive fieldwork and available access to the geological maps.

2.1 Spectral Properties of Gypsum

The spectral signature of the gypsum samples was done by using Spectroradiometer (ASD), FieldSpec3 at the Remote Sensing Center, University of Mosul. The reflectivity of each sample was measured as a function of wavelength. The spectral range of this device covers the bands within the range 350 - 2500 nanometers. The spectral signature of the front face of the rock models showed a high reflectivity in the visible and short infrared spectrum compared to the rest of the bands within Rapid-Eye bands (Fig. 2).

The water absorption bands take place at the lengths 1400, 1750, 1900 and 2500 nanometers. The absorption is due to bending and stretching combinations of the H₂O molecule or O-H bending and stretching or S-O bending overtones, therefore the spectral bands of any sensor of satellite characteristics to such absorptions wavelengths have the potential to map gypsum occurrences (Clark et al., 1990; Crowley, 1991; Cloutis et al., 2008; Rajendran and Nasir, 2021 and Thannoun, 2021). Also, abnormal reflectivity of the samples was seen at the wavelength 1875 nanometers. It is clear that the spectral signature increases with the increase of the wavelength from the visible range to near infrared NIR according to the spectral bands used in the Rapid-Eye satellite images. The other objective of this study is to determine the possibility of adopting bands of close reflectivity for gypsum rocks within visible and near-infrared ranges to discriminate layers of the Gypsum rocks.

2.2. Satellite image and software

The Satellite images characterized with five bands and a spatial resolution 5 meters are used in order to distinguish the gypsum rock from other units within the study area (Table 2). The ENVI, and ArcGIS are the main software’s used in this study.

2.3. Image Processing

Image processing methods are a critical way to improve satellite data in several ways. These methods are adopted in order to obtain the best distinction of gypsum rocks from other rock units. FCC
and Image transformation methods represented by MNF and PCA are the digital processing operations adopted.

<table>
<thead>
<tr>
<th>Table 2. characteristics of Satellite image.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type Resolution</td>
</tr>
<tr>
<td>Swath Width</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Band</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

2.3.1. FCC (False Color Composite)

The composite of bands 3, 2, and 1 as RGB displays true color, while the false-color composite is any other RGB display. A large number of FCC images can be formed. This method is used to improve some features that may be invisible or blurred within the spectral range of the human eye. Different FCCs can be used to highlight different rock units with other features on the image.

2.3.2. Transformation Methods Images

Image transformation methods represented by MNF and PCA are the digital processing operations adopted. In hyperspectral imaging, the presence of noise is a common issue that has been extensively studied in various research attempts. Numerous methods have been proposed to address this challenge, as evidenced by the works of Qian et al. (2008) and Syarif and Kumara (2018). The Minimum Noise Fraction (MNF) technique is serving the purpose of noise segregation and reducing computational requirements for subsequent processing (Joseph, 1994). MNF operates by transforming a noisy data cube into output channel images with progressively increasing noise levels, resulting in a corresponding decrease in image quality, (Luo et al., 2016). This ordering of components based on image quality is a distinguishing characteristic of MNF (Green et al., 1988). In the context of assessing the spatial variability of different rock units using surface reflectance data, MNF is applied alongside the Principal Component Analysis (PCA) to mitigate redundant information present in highly correlated bands, (Gasmi et al., 2016). Unlike other traditional methods, PCA yields uncorrelated output data, thereby providing more detailed information (Jensen and Lulla, 1987). While MNF and PCA share similarities in their procedures, the key distinction lies in MNF's consideration of noise and PCA's focus on variation of data.

2.4. Field Verification

Fieldwork conducted in February 2020 showed a wide spread of gypsum rock layers within the Middle Miocene Fatha Formation. The field verification was including sampling of gypsum for the purpose of measuring their spectral reflectivity. GPS ground points are used as well, to match the boundary of gypsum units with other units and interpret images also with maps and previous studies.

2.5. X-ray fluorescence and X-ray diffraction

A series of sampling collections of gypsum from the Fatha Formation are carried out at the Qara Darbendi Anticline site (Fig. 1). Total of 21 representative rock samples are collected. These samples undergone the laboratory analyses, like powdering, XRF, and XRD analyses to support the integrated
image transformation methods processing. The representative elemental and mineralogical rock sample compositions are determined at the Center for Scientific Research, University of Soran. The mineralogical composition of the bulk samples is determined using the PAN analytical X'PertPRO (CuKα = 1.5406) X-Ray Diffraction (XRD). The XRD data is obtained with a scanning rate of 1°/min in the 2θ range from 5 to 70°. Additionally, the elemental composition of the same samples is determined using the SKYRAY portable X-Ray Fluorescence (XRF).

3. Results and Discussion

3.1. Gypsum determined by FCC images

Multiple false color images can be superimposed by the five spectral bands of Rapid-Eye images. It is clear that gypsum rocks have a high reflectivity compared to the surrounding rocks within most of the bands adopted in the recent study (Fig. 3). The study revealed that the FCC (R:3, G:4, and B:1) was developed as best FCC image for isolate and mapping the gypsum rocks within selected area. In this composition, the exposed gypsum layers appear in a bright white color and are very distinctive from the other types of surrounding rocks (Fig. 4).

![Fig. 3. Bands used in this study.](image)

3.2 Gypsum verification utilizing image transformation methods:

The image transformation method is rarely approved by researchers compared to the band ratio method. Several scholars have relied on satellite data with wide different spectral ranges, while the recent study relies on close spectral ranges, and this is what the Rapid Eye satellite data provide. However, it has been proven through the results that give it high efficiency in isolating the different rock units from each other. The results of MNF images showed that gypsum rocks have high reflectivity within band 1 and very little reflectivity within bands 2, 3 and 4, while band 5 gave almost equal reflectivity to the lithological rock units (Fig. 5). The MNF composites (R:1, G:2, B:3 and R:4, G:3,
B:2) image was selected as the best two images to show a distinct distribution of the gypsum layers in the exposed studied area (Figs. 6 a and b).

**Fig. 4.** False color composite FCC (R:3, G:4, B:1) as best image to mapping gypsum rocks.

**Fig. 5.** Gray images of the MNF method.

To establish the boundary of the gypsum unit, GPS ground points are utilized to compare and align the unit with others. This comparison is done by considering field work observations, interpreted images, maps, and previous studies. According to the number of supported distinct bands, the results show a number of outputs for the components of PCA (Fig.7). The first PC (PC1) contains the largest percentage of information and the second PC (PC2) contains the second-largest information, and so on.
Furthermore, the PC1 and PC2 gave more information and details about the geological formations than the others (Table 3).

**Table 3** shows the Eigenvalues of PC.

<table>
<thead>
<tr>
<th>Eigenvalue Number</th>
<th>Eigenvalues</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9309912.040421</td>
</tr>
<tr>
<td>2</td>
<td>393215.822862</td>
</tr>
<tr>
<td>3</td>
<td>148758.502741</td>
</tr>
<tr>
<td>4</td>
<td>34148.612688</td>
</tr>
<tr>
<td>5</td>
<td>14667.495074</td>
</tr>
</tbody>
</table>

**Fig. 6.** Color composites of the MNF (a- R:1, G:2, B:3, b- R:4, G:3, B:2).

**Fig. 7.** Principal components (PC) bands of the selected area.
PC bands produce more colorful composite images than spectral color-composite images because the data is uncorrelated (Chuvieco, 2016). Many false-color images can be obtained from PCA, which can be supported that the best RGB composition is R: 3, G: 1, B: 2 where the layers of gypsum rocks appear clearly in bright white color (Fig. 8).

Fig. 8. Shows the color composites of the PCA (R:5, G:2, B:1) image.

3.3 Fieldwork Observation

Fieldwork was conducted in February 2020 as follows:

The primary objectives being the determination of ground truth for gypsum rock exposures using GPS. The GPS points were projected onto the output images to verify the accuracy of the results. The findings revealed a significant possibility of digital manipulation in delineating and distinguishing the boundaries between the gypsum layers and other rock formations. Fig. 9 represents the studied rock facies from the intensive fieldwork.

Fig. 9. Gypsum layers photos from fieldwork.
ASD field Spectradiometer is conducted on a number of samples with a full-range (i.e., 400nm to 500nm). To classify the satellite imagery, the Spectral signature of the gypsum samples and Rapid-Eye bands are used (Fig. 2). Spectral Angle Mapper classification is used to extract gypsum outcrops from the satellite imagery. The method is a physical-spectral classifier that utilizes an n-dimensional angle to match reference spectra-pixels (Kruse et al., 1993). The classification algorithm relies on the assumption that each pixel in the images reflects a specific ground target material and can only be assigned to one ground class. This method determines the spectral similarity between the pixel's spectrum and a reference spectrum by measuring the angle between them. The endmember spectra used in SAM classification can be obtained from ASCII files generated by ASD field spectroradiometers, spectral libraries, or directly extracted from image pixels. The Spectral Angle Mapper (SAM) is a measurement technique that compares the angular spectra of data points, represented by the spectra angle (θ). SAM detects the spectral similarity by applying the following equation (Kruse et al., 1993):

$$\alpha = \cos^{-1} \left[ \frac{\sum_{i=1}^{n} t_i r_i}{\left( \sum_{i=1}^{n} t_i^2 \right)^{1/2} \left( \sum_{i=1}^{n} r_i^2 \right)^{1/2}} \right]$$

Where: \( t \) = the pixel spectrum, \( r \) = the spectrum referee, and \( n \) = the total number of available bands.

SAM focuses on the angular differences between spectra rather than their magnitudes. It is worth noting that SAM is relatively insensitive to illumination and albedo effects, (Falcone and Gomez, 2005; Thannoun et al., 2018; Thannoun, 2021). Landsat 7 imagery was used after corrected by the FLASH atmospheric correction modular. The output classified image by the SAM classification is shown in Fig. 10.

![Fig. 10. A. FCC of landsat-7, B. Color-coded image of SAM classification, C: Same classification draped on FCC image.](image-url)
It can be noticing the gypsum rocks are accurately separated based on the laboratory measured reflectivity and matched with the reflectivity of gypsum rocks in the satellite image.

### 3.4 Mineralogical and elemental evaluation of the Gypsum

Verification of the collected gypsum samples is done by applying the XRF, and XRD analyses to support the integrated image transformation methods processing. The result of bulk geochemical composition, both elemental and mineralogical analyses of 21 samples shows a dominant elemental composition of S, Mg, Ca…, and the major mineral composition are Gypsum, and Bassanite (Table 4). Elemental and mineral compositions at the Qara Darbandi Anticline site are dominated by gypsum, anhydrite, and calcium sulfate mineral with the exception of two samples, which do not contain evaporite minerals with minor concentrations of dolomite, montmorillonite, clay minerals (Fig. 11). The high quartz content is characterized of two samples, in places a zeolite mineral is also recognized. Gypsum and Bassanite as mineral and sulfur as element are the dominant compositions in all samples. The dominant of gypsum and Bassanite represented the primary composition of Fatha Formation, while anhydrite, dolomite, quartz, calcite in some samples occupy the majority contents, with high percentages of S, Mg, Si and Ca elemental composition. Minor mineral and elemental phases from the same site include clay minerals, Fe, Ni, Cu, Zn, Sr, Y, Zr, Nb, Mo, Ag, Cd, Sb, K, and Pb are indicated as well. These minor compositions are a product of later diagenetic settings (Salih et al., 2021), and/or due to hydrocarbon-induced (Salih et al., 2023) under normal conditions.

#### Table 4. Bulk quantitative composition of studied samples from Qara Darbandi Anticline site.

<table>
<thead>
<tr>
<th>SN</th>
<th>mu2</th>
<th>mu12</th>
<th>mu3</th>
<th>mu8</th>
<th>mu7</th>
<th>mu10</th>
<th>mu6</th>
<th>mu5</th>
<th>muL</th>
<th>mu9</th>
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<td>34.9</td>
<td>41.9</td>
<td>25.7</td>
<td>39.2</td>
<td>38.6</td>
<td>31.5</td>
<td>42.1</td>
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<td>Al₂O₃</td>
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<td>11.4</td>
<td>10.3</td>
<td>11.1</td>
<td>9.9</td>
<td>13.8</td>
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<td>SiO₂</td>
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<td>20.2</td>
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<td>13.6</td>
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<tr>
<td>Zn</td>
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<td>0.4</td>
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<td>0.02</td>
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<td>0.01</td>
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<td>Nb</td>
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<td>0.17</td>
<td>0.2</td>
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<td>0.08</td>
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<td>0.1</td>
<td>0.1</td>
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5. Conclusions

The results show the efficiency of applied digital processors in determining the locations of gypsum and to some extent the covered gypsum layers with recent sediments.

The method of FCC displays a qualified possibility of drawing the boundaries of gypsum rocks, as well as the possibility of detecting them in the surrounding areas. Image transformation methods,
represented by MNF and PCA prove highly efficient images in isolating the exposed layers of gypsum rocks. Also, the results revealed the possibility of adopting bands with close reflectivity in the process of separating the rock units from each other, as most of the bands adopted in this study were of relatively high reflectivity.

The findings of the GPS during fieldwork revealed a significant possibility of digital manipulation in delineating and distinguishing the boundaries between the gypsum layers and other rock formations. The Spectral Angle Mapper classification and the Landsat 7 imagery after being corrected by the FLASH atmospheric correction modular are used to extract gypsum outcrops from the satellite imagery. It can be noticing the gypsum rocks are accurately separated based on the laboratory-measured reflectivity and matched with the reflectivity of gypsum rocks in the satellite image.

Verification of the collected gypsum samples by applying the XRF, and XRD analyses reflect that Gypsum and Bassanite as minerals and sulfur as an element are the dominant compositions in all samples representing the primary composition of Fatha Formation.

Minor minerals including clay minerals are products of later diagenetic settings, and/ or due to hydrocarbon-induced under normal conditions.

References


