The use of Remote Sensing Technology in geological Investigation and mineral Detection in El Azraq-Jordan

L'utilisation de la télédétection technologie dans l'investigation géologique et la détection minérale dans la région de EL Azraq

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Introduction

Remote Sensing Techniques have opened a new era in mapping lithology. The Landsat Enhanced Thematic Mapper data are extremely useful. In the past, the geological maps are prepared from conventional ground surveys based on field observations. They are made along traverse lines at regular intervals. While plotting such point information collected along the traverse lines on the topographic base and ultimately preparing final maps by extrapolating the details, certain errors are unavoidable and lead to inaccuracies in maps. Since the development of remote sensing technology, the mapping procedures have undergone continuous change. Now remote sensing techniques play an important role in mapping programs (Farina et al. 2005). Mapping of lithology and alteration zones in inaccessible mountain and forest terrain has always posed a challenge. There always existed disputes on the accuracy of lithological boundaries and structural details in these maps. Vast area to be surveyed and its inaccessibility, forbids physical investigation of every outcrop. At this juncture, the potential of RS is appreciable. The greatest advantage of RS is the synoptic view that it provides. It gives a regional and integrated perspective of inter-relations between various land features. The availability of multi-spectral and high resolution data as well as the advanced capabilities of digital image processing techniques, in generating enhanced and interpretable image has further enlarged the potential of RS in delineating the lithological contacts and geological structure in great
details and with better accuracy (Drury 1987). The existing multi-spectral satellite systems are designed to investigate natural resources with special focus on vegetation coverage, lithology and mineral exploration (Crippen and Blom 2001; Yousef and Shedid 1999; Abrams 1984). The wide area coverage of the data in connection with their long-term availability allows analysis of the spatial dynamics within larger areas. Most applications of RS in geology involve the delineation of structures, discrimination of different rock and soil types and resource exploration (Kruse and Dietz 1991). Following the launch of Landsat Thematic Mapper (TM) in 1982, geologists gained access to better spatial (30m) and spectral resolution (Abrams 1984), compared to the Multi spectral Scanner (MSS) used, for detailed geological studies (Podwysocki et al. 1983). Many geological studies have employed TM and ETM+ data to discriminate the various lithologies, lineaments and minerals by using hyper-spectral laboratory (Abrams, 1984). In the regions where bedrock is exposed multi-spectral RS is useful for mapping lithology and alteration zones. Subsequent Studies, in South-West USA and elsewhere (Prost 1980; Rowan and Kahle 1982; Podwysocki et al. 1983; Abrams 1984) have confirmed that areas of hydrothermal alterations may be distinguishable using the ratio of TM band 5 and 7. Also it is evident that the spectral characteristics of TM bands are suitable for mapping lithology.

The objective of this work is to carry out a lithological and structural study of El-Azraq area as well as minerals exploration using RS techniques.

**Studied Area**

El-Azraq is located in the north-eastern part of Jordan (Figure 1), and extends from EL Azraq to Artin Mountain in the North; it’s about 1330 km². El-Azraq is an arid zone with a small oasis. It is a part of El-Zarqa underground basin considered the main source of water supply for more than the half of Jordan population (Ministry of Water and Irrigation 2002).
The geological maps at scale of 1:250,000 and 1:50,000 show that the area is covered mainly by sedimentary and igneous rocks (Geological Survey of the Federal Republic of Germany 1968; Ibrahim 1996) (Figure 1).

(i) Sedimentary rocks:

The bedrock in the mapped area comprises part of the Balqa Group, and consists of:

- The Umm Rijam Chert Limestone formation- middle Eocene
- Pleistocene Fluvial deposits, occurs in the central southern part of the area, and overlies the Umm Rijam Chert Limestone Formation. These deposits occupy a restricted area and form a flat zone with a thin cover filling the local fragments.
- Alluvial deposits, Wadi deposits and mudflat comprise the most recent phases of deposition which are composed of pelitic sediment, sands, silt and basaltic fragments.

(ii) Igneous Rocks

Important part of study area is covered by these rocks, dominated by the Neogene’s Quaternary basaltic rocks. These rocks are divided in three types:

- Abed Olivine Basalt Formation (late Miocene): This flow is characterized by hummocky, small hills, rough, blocky with larger irregular boulder shape.
- Salaman Basalt (late Miocene); It forms a flat area, with small boulders.
- Madhala Basalt (Plio-Pleistocene): It is characterized by smooth surface.

Methodology

A cover of remotely sensed data: LandSat ETM+ (02/Sep/2002) 173/38 and SAR Images Radar Sat (28/October) 1996 were used. The LandSat images were chosen for their large spectral resolution and their appropriate spatial resolution. SAR image was used to provide information about the texture and topography of the ground surface. The Radar
waves response depends on (i) the topography and roughness of ground (ii) the moisture and (iii) the chemical and physical characteristics of soil. So, it is important for mineral, lithological and geological exploration. The capture dates are not very important due to the aridity of the study area. The images were geometrically corrected and represented in UTM projection, WSG84, using topographic maps at scales 1:50,000 and 1:100,000 (Royal Jordanian Geographic Center 1992) with an output pixel size of 30 meters. The Geological maps at scale 1:250,000 and 1:50,000 were scanned and corrected. The PCI-Geomatica software was used for digital image processing. This provided useful lithological, structural and mineral information. Figure 2 described the followed methodology.

**Figure 2: followed flowchart**

**Investigating the lithology**

For investigating the lithology in the studied area, the Thematic Mapper images have been used after being digitally processed in order to achieve maximum lithological differentiation. Digital numbers have been atmospherically corrected by the dark pixel subtraction method. Several different image analysis techniques were studied, in order to understand which technique and/or techniques are the most suitable for lithology discrimination. Various image processing procedures were applied such as: ratioing and PC analysis. These different types of digital image processing allow the evaluation and the contribution of RS in lithological field. On the other hand, these techniques show the benefits of these tools in such application.

For investigating the lithology in the studied area, the use of some spectral processing techniques was necessary to prove the efficiency of R.S. in this Field. A linear contrast stretch with atmospheric correction was sufficient to produce an image of high quality. A linear transfer function was used to make full use of the 256-output value. Enhanced
images of single band or false-color images comprising three contrast stretched bands can then be interpreted geologically. Figure 3 shows the color composite of bands 7, 4 and 2 after enhancements.

![Enhanced Landsat ETM+ (bands 7, 4 and 2) showing the main geological formations in the study area](image)

**Figure 3**: Enhanced Landsat ETM+ (bands 7, 4 and 2) showing the main geological formations in the study area

**The use of Principal Component Analysis for investigating the lithology**

The Principal Component (PC) Analysis process allowed the extraction of new information. It shows the directions of grey levels distribution in feature space. In general, PC analysis is a statistical technique widely used in RS to choose the suitable bands and to show spectral differences which helps to display clearly the correlation of the spectral values between the different channels. Due to the large number of spectral bands, much information was acquired from LandSat ETM+ images, especially in the infrared region of the spectrum. As result, these data were very useful for lithology, soil and terrain pattern differentiation. After Principal Component transformation, using linear and nonlinear adaptive stretches, visual inspection of the PC color composites indicates that the composite containing the first three PCs were the most informative mainly for the basalt formation (Figure 4).
As we can see in this figure, the white color represents the Salaman Basalt, while the gray color represents the Madaba Basalt. Meanwhile, the Abed olivine is represented by the light gray; and the tuff appears in black color.

The use of Ratioing Analysis for investigating the lithology

For Lithological and alteration mapping, ratio images were used in this study. They were prepared by dividing the digital number (DN) in one band by the corresponding DN in another band for each pixel, stretching the result value and plotting the new values as an image. This method is used by (Weissbrod et al. 1985; Cappicciioni et al. 2003; Edgardo 1992) to extract spectral information from multi-spectral imagery. Color Composite of ratio images 3/1, 5/7 and 3/5 (RGB) express more geological information and provide higher contrast between units than the conventional color images (Figure 5).
The red color in Figure 5 represents the tuff, while the pink color represents the Madhala Basalt. The limestone appears in a greenish color; meanwhile the Abed Olivine Basalt appears in blue color.

**The use of IHS transformation for investigating the lithology**

For cover type discrimination, the IHS transformation has been successfully applied to ETM+ data; it presents colors more nearly as they are perceived by humans (Buchanan 1979). It is a system based on the color sphere in which the vertical axis represents intensity, the radius represents saturation, and the circumference represents hue. The intensity represents brightness variations, saturation represents the purity of color or amount of white, and hue represents the dominant wavelength of color. IHS image was prepared from ETM+ bands 1, 5 and 3 for the study area (Figure 6). The volcanic cone is discriminated easily due to its dark red color.
Investigating the lineaments:

The previous techniques of digital image processing proved that RS is useful in mapping lithology and offers an efficient tool for detecting geological structures, such as lineaments. Other techniques were also applied to emphasize the role of RS in detecting lineament. The spatial filtering and data fusion between SAR image and LandSat were powerful for the extraction of Lineaments in the study area.

The use of filtering for investigating the lineaments

The filtering technique is commonly used to (i) restore imagery, (ii) enhance the images for visual interpretation and (iii) extract features using local spatial frequency. Applying a spatial filter on an image means that the value at each output pixel is the average of a small neighborhood of input pixels. The obtained image represents the difference between each original pixel and the average of its neighborhood. The directional filter is a spatial filter very useful for detecting the oriented features such as lineaments and emphasizing higher spatial frequencies (Robert, 1997). The following matrixes are examples of some directional filters.

\[
\begin{pmatrix}
-1 & 2 & -1
\end{pmatrix}
\quad
\begin{pmatrix}
-1 \\
2 \\
-1
\end{pmatrix}
\quad
\begin{pmatrix}
-1 & 0 & 0 \\
0 & 2 & 0 \\
0 & 0 & -1
\end{pmatrix}
\]
Different directional filters were applied on ETM+. The best results were obtained for band 5 using the following matrix:

\[
\begin{pmatrix}
-1 & 0 & 0 \\
0 & 2 & 0 \\
0 & 0 & -1 \\
\end{pmatrix}
\]

We know that the vegetation effect on the spectral responses in this band is minimized. The Sobel filter was also a powerful tool for detecting the lineament; it consists on the application of the following matrix:

\[
\begin{pmatrix}
1 & 0 & 1 \\
2 & 1 & -2 \\
1 & 0 & -1 \\
\end{pmatrix}
\]

\[
\begin{pmatrix}
-1 & -2 & -1 \\
0 & 1 & 0 \\
1 & 2 & 1 \\
\end{pmatrix}
\]

**In x direction: In y direction:**

The visual inspection allowed the identification of the lineament in this region. A remotely sensed lineament map (Figure 7) was produced depending on directional filters and edge enhancement.

![Image](image.png)

**Figure 7**: Image after applying directional filtering allowing the extraction of the main lineaments in the study area

The use of data fusion technique for investigating the lineaments

The data fusion images are very useful for the geologic mapping of structures and lithology (Al Rawashdeh, 2003; Schetselar, 2001). Radar data can be easily integrated with
other data sets, thus creating an enhanced interpretive mapping tool. The data fusion
between SAR and optic images provides information about topography, texture chemical
and physical characteristic of the ground surface and subsurface as well as about land
cover types. SAR image was enhanced and geometrically corrected using the corrected
LandSat ETM image. A transfer of LandSat image from RGB color to IHS was carried out
using bands 7, 4 and 2. Then, the obtained IHS image was newly transformed to RGB in
replacing the intensity channel (I) by SAR image. A lineament map was extracted after a
linear stretch processing of the new image (Figure 8). The final image retains most of the
multi-spectral information and accentuates terrain features from SAR Image.

Figure 8: Data fusion between SAR and ETM+ images, showing the geological, structural and
lithological elements in the study area.

Investigating the mineral detection:

The use of principal component and Filtering for mineral detection

RS is largely used for mineral exploration (Rowan and Bowers 1995; Abdel-hamid and
Rabba 1994; Kaufmann, 1988; Abrams,1984; Rowan and Kahle, 1982), especially for (i)
mapping regional lineaments, (ii) mapping local fracture patterns that may control
individual ore deposits, (iii) detecting hydro-thermally altered rocks associated with ore
deposits, and (iv) providing basic geologic data. Various digital image processing
procedures were applied such as ratioing, PC analysis. The ratio of ETM+ Band 3 to Band 1
(3/1) renders most of the area in rather dark gray or bright grey, which corresponds to
zones of strong hematitic alteration. The Spectral response of the weathered iron
minerals has weak reflectance in the blue region (band1) and strong reflectance in the
red region (band 3), so the ratio 3/1, which has high values can be used for iron oxide.
The ratio 4/2 is similar to 3/1 but the bright areas appear displaced. This can be explained by the existence of vegetation or organic materials.

Absorption caused by kaolinite, montmorillonite and clay minerals results in low reflectance in band 7 and high reflectance in band 5. So, the ratio image 5/7 would have bright signatures for clay minerals. Unaltered rock in bands 5 and 7 are identical in brightness. This brightness is equal one in the case of ratio image for ferrous minerals; the best ratio image was 5/ 4 (Figure 9).

Figure 9: Ratio image 5/4 enables the discrimination of ferrous minerals as white color in the study area

The use of selective Principal Component for mineral detection

A Selective Principal Component Analysis (SPC) of ETM+ was applied using band 1, 3, 4 and 5. These bands were used in mapping iron and iron oxide bearing minerals in the study area. ETM+ band 7 was particularly excluded to avoid contribution of hydroxyl bearing minerals. The SPC from the previous bands highlights iron oxide bearing minerals as bright pixels on the image of grey color (Figure 10). The same method was applied using bands 1, 4, 5 and 7. It highlights the hydroxyl bearing minerals as dark pixels on the grey image (Laughlin, 1991). It is to be noted that the use of selective bands of LandSat ETM+ in principal component Analysis were very useful in obtaining adequate results for the following reasons:

Only uncorrelated bands will be used, this leads to no redundancy and to get satisfied results;

Using different PCA's lead to different results; this enhances the results and revealed the faults and lineaments clearly.
Figure 10: Image obtained by Selective Principal Component technique highlighting the hydroxyl bearing minerals as dark pixels

Conclusion

This study showed that Remote Sensing techniques are an efficient tool for geological mapping. Different processing techniques were applied to the LandSat ETM+ and SAR images to discriminate and delineate the lithological units and regional lineaments. Moreover, Remote Sensing has proved a valuable aid in exploring mineral resources.

The Principal Component analysis and the directional filters applied to data obtained by merging ETM+ with SAR images were very useful for lineament extraction. The Selective Principal Component analysis, band ratioing, and hyper spectral techniques allowed the discrimination of altered areas and the detection of minerals.

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**ABSTRACTS**

This study examines the use of Remote Sensing (RS) technology in geological studies in El Azraq area. LandSat Enhanced Thematic Mapper plus (ETM+) and Radar SAR images were used to (i) classify the various geological units found in El Azraq area located in the North-East of Jordan, (ii) discriminate the lithology and structure of this area, and (iii) delineate the associated zones of hydrothermal alteration. A wide variety of digital image processing techniques were applied such as the Principal Components (PC) analysis, ratioing and Intensity, Hue and Saturation (IHS) transformation. The color composite of Principal Components (1, 2, and 3), the ratio images (3/1, 4/3, and 5/7) and the IHS (1, 3, 5) enabled us to determine the different types of igneous rocks in the study area. A remote sensed lineament map was produced using two different methods: (i) application of directional filters and edge enhancement; and (ii) data fusion of ETM+ with SAR image. The selective PC analysis of ETM+ using bands 1, 3, 4, and 5 was used in mapping iron and iron oxide bearing minerals. The same method was also applied using bands 1, 4, 5, and 7 for hydroxyl bearing minerals detection. Finally, the hyper spectral technique was used for detecting the different minerals in the study area based on the spectral library of minerals.

Cette étude examine l'utilisation de la technologie de télédétection dans des études géologiques dans la région de EL Azraq en Jordanie. 'LandSat Enhanced Thematic Mapper plus' (ETM+) et les images Radar SAR ont été employés pour (i) classifier les diverses unités géologiques trouvées dans la région de EL Azraq située dans le nord-est de la Jordanie, (ii) discriminer la lithologie et la structure de ce secteur, et (iii) tracer les zones associées de l’alteration hydrothermique. Une grande variété de techniques de traitement d’image numérique ont été appliquées comme l’analyse des composants principaux (PC), les rapport spectrale (ratioing) et la transformation d’intensité, de tonalité et de saturation (IHS). Le composé de couleur des composants principaux (1, 2, et 3), les images de rapport (3/1, 4/3, et 5/7) et l’IHS (1, 3, 5) nous a permis de déterminer les différents types de roches plutoniques dans le secteur d'étude. Une carte de linéament a été produite en utilisant deux méthodes différentes : (i) application des filtres directionnels et du perfectionnement de bord ; et (ii) fusion de données d’ETM+ avec l’image de SAR. L’analyse sélective de PC d’ETM+ en utilisant les bandes 1, 3, 4, et 5 a été employée en traçant des minerais.
de roulement de fer et d’oxyde de fer. La même méthode a été également appliquée en utilisant les bandes 1, 4, 5, et 7 pour la détection de minerais de roulement d’hydroxyle.

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