A Comparative Analysis of Lineaments Extracted from Landsat 8 OLI & ASTER-GDEM Data, in Talmakent Area, Western High Atlas, Morocco

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Abstract

Structural mapping by remote sensing is an essential component to completing the geological mapping of the Talmaknet region. It allows us to understand the regional tectonics of the southernmost segment of the Hercynian of Western Morocco, exploiting Geographic Information Systems (GIS) and satellite imagery processing techniques in order to obtain a good lineament discrimination. To this end, the approach adopted was based on preliminary processing of Landsat 8 OLI satellite imagery combined with a morpho-structural shading analysis technique, using the Digital Elevation Model (DEM), and applying several techniques of image enhancement and directional filters to the different treatments to improve the visibility of the linear structures in the images. Given the interesting number of fractions collected, a statistical and directional study was carried out on the synthetic maps to show the distribution and orientation of the lineaments. This analysis indicates a dominant NE-SW oriented geological fracturing, which agrees with the existing geological data in the area, confirming the effectiveness of GIS and remote sensing techniques in structural geology studies, especially to have a detailed mapping of the linear structures in the study area.

Keywords: Lineaments; Structural mapping; GIS; Remote sensing; DEM

1. Introduction

Structural mapping allows identifying and characterizing the structural expression of the earth's surface such as faults, folds, and lineaments. Their detection plays an interesting part in diverse disciplines to solve many problems. Such purposes as site selection the construction of dams, bridges, roads, seismic and landslide hazard assessment (Stefouli et al., 1996), mineral exploration (Rowan & Lathram, 1980), for thermal spring detection and hydrogeological research, for structural geological studies (Rahiman & Pettinga, 2008), and tectonic geomorphology (Shahzad & Zegeye, 2009), in all these mentioned cases, the structures of the lineaments must be precisely defined.

The arrival of satellite images has facilitated the process of geological mapping, especially in inaccessible areas. They are considered pre-eminent tools to differentiate lineaments, and to obtain more information. They have become essential, indispensable, fast and accurate mapping tools that allow the use of multiple techniques for lineament characterization as opposed to conventional mapping, which is costly and time consuming. These remote sensing data have been widely used for lineament mapping (Dubois, 2001; Ranganai & Ebinger, 2008; Corgne et al., 2010; Hashim et al., 2013) including Landsat

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The objective of this study is the use of satellite imagery OLI and ASTER GDEM updated covering the whole territory of the study area (Abrams et al., 2015), for the mapping and analysis of fracture systems in the region. In the process of this study several treatments were carried out namely; the Principal Component Analysis (PCA), Directional Filtering on the near infrared band of OLI imagery, and morpho-structural analysis techniques of Aster global digital elevation images. Additionally, the project worked on an automatic extraction process of the filtered lineaments, followed by verification, comparison, and statistical analysis of the different methods for a clearer view of the fractured environment.

2. Materials and Methods

2.1. Geological Context

The area presents a key region in the geology of Morocco since it is located at the boundary between the "structured Paleozoic", Western High Atlas and the Atlantic High Atlas. It is in a rural commune of the province of Taroudant, Souss-Massa-Drâa region in Morocco (Fig.1). The region is a mountainous area whose altitude exceeds 3000m (Adrar-n-Dern ‘3025m’, jebel Tinergwet ‘3434m’), with an arid, hot and dry climate.

Fig.1. Location of the study area : A. Africa; B. Morocco; C. Digital Elevation Model of the study area

2.1.1. Lithostratigraphy

The geology of the study area is part of the geological history of the Western High Atlas. It is located almost in the axial zone of the Paleozoic High Atlas that is limited to the north by the Haouz plain and the Haha basin and to the south by the Souss plain. The study area consists of outcrops of Paleozoic age deformed to Hercynian, with a Mesozoic and Cenozoic cover discordant to the previous set (Fig. 2).
The Paleozoic terrains comprise the vast majority of exposures ranging from the Lower Cambrian to the Upper Devonian (Cornée & Tayebi, 1987), they are involved in the Hercynian structuring of the region where two major Hercynian structural domains are distinguishable (Cornée, 1989; Tayebi, 1989; Cornée et al., 1990).

- An autochthonous unit located in the southern part of the eastern zone that has an Anti-Atlas type facies, consisting of the slightly folded Lower Cambrian (Cornée & Tayebi, 1987).
- A relatively allochthonous unit found in the east, also constituted by the Cambrian, which corresponds to an anticlinal bulge; this megastructure is cut by several fault systems of unequal importance.
- A frankly allochthonous unit with certain clippers to the NW of the sector. It includes the allochthonous outcrops of Aït Tounart (Cornée et al., 1990) and the clippers of Azour Warg and Says Warab resting on the preceding unit of relative allochthonous. This unit is lightly tectonized and metamorphosed.

The Mesozoic terrains are represented by the Permo-Triassic, which outcrops in the west and at the northwestern end of the area contain outcrops attributed to the Permian and Triassic. In addition to volcanic and sedimentary formations, the area includes intrusive rocks in the SE portion that occur as basic and acidic plutons and/or dykes.

Cenozoic soils that correspond to Quaternary deposits consist of two terraces. The first terrace consists of silts with cobbles at the base, and the second one consists mainly of cobbles and alluvial fans, as well as slope breccias and slope aprons (q2C, q3C) that are quite numerous in the study area.

2.1.2. Tectonic Phases

Tectonically, the Paleozoic terrains are part of the outer zone of the strongly deformed Hercynian chain. They were affected by Hercynian deformations accompanied by regional metamorphism and the emplacement of granitoid intrusions such as Tichka (Pique, 1994). The sector, similar to the whole High Atlas, was exposed during late-Hercynian surge; with major directions NS-EW and NE-SW to E-W, and the atlas system; where two phases can be identified, generating two Cleavage visible on the ground and several brittle phases.

The impact of the Atlantic tectonics on the region is represented by normal faults with a NE-SW orientation and or reverse faults with an NW-SE and WNS-ESE orientation (Schaer, 1967; Michard 1976; Tayebi M. 1989). This orogeny divided the region into a series of blocks (horsts and grabens) where the basement (Palaeozoic and locally Proterozoic) remained more or less rigid (Michard, 1976). Traces of these tectonic movements, linked to the Atlas orogeny, are found in the western part of the region, near the Argana corridor (intra-continental basin controlled by active NE-SW faults with normal play).
2.2. Data Sources

This work is based on the application of various remote sensing methods for structural mapping, followed by a controlling and a validation of the obtained results using the topographic funds and previous work carried out in the study area. In addition to a frequency analysis of the different fracture directions in the study area (Fig. 3).

The first relevant step is to select the initial input data, which were obtained from the Landsat 8 OLI high-resolution satellite that records data in nine spectral bands ranging from visible to mid-infrared (Table 1). The total coverage of the area required the scene 192-053, acquired on July 8, 2020, during the dry season, with a Universal Transverse Mercator projection UTM North, Zone 29, World Datum WGS 84.

Table 1. Spectral Bands of Landsat OLI of used data in this study (NASA).

<table>
<thead>
<tr>
<th>Spectral Bands</th>
<th>Wavelength (micrometers)</th>
<th>Resolution (meters)</th>
<th>Radiometric Resolution (Bit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 1 - Coastal aerosol</td>
<td>0.43-0.45</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Band 2 – Blue</td>
<td>0.45-0.51</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Band 3 – Green</td>
<td>0.53-0.59</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Band 4 – Red</td>
<td>0.64-0.67</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Band 5 – Near Infrared</td>
<td>0.85-0.88</td>
<td>30</td>
<td>16</td>
</tr>
<tr>
<td>Band 6 – SWIR 1</td>
<td>1.57-1.65</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Band 7 – SWIR 2</td>
<td>2.11-2.29</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Band 8 – Panchromatic</td>
<td>0.50-0.68</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Band 9 – Cirrus</td>
<td>1.36-1.38</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>
The second datasets acquired are the cartographic backgrounds established at a scale of 1:50000, consisting of geological maps published by the Ministry of Energy and Mines, which were used to create the mapped fracture network of the region, and topographic backgrounds to extract the hydrographic, road and electrical networks.

The Global Digital Elevation Model of the Advanced Spaceborne Emission and Reflection Radiometer (ASTER GDEM) with a spatial resolution of 30 m will also be used to make the Shaded Relief.

2.3. Methodology

Because of the nature variety of the earth's surface materials and its varying elevation topography, it is recommended that different lineament extraction processing techniques be used. For this reason, three techniques are commonly used to map the maximum fractions that affect the study area. These image processing techniques have been applied to Landsat 8 OLI data, PCA and digital elevation data to produce shaded images (Fig.3).

2.3.1. Image Landsat OLI

First, due to atmospheric disturbances and topographic effects, a set of radiometric and atmospheric corrections are applied to the Landsat 8 OLI image to reduce the uncertainty of the data. Regarding, the extraction of lineaments, we opted for the processing and interpretation of the near-infrared band NIR of the Landsat OLI satellite with a spatial resolution of 30, a radiometric resolution of 16 bits, and a wavelength of 0.851-0.879um, this band is often used for the study of geological structures (Si Mhamdi et al., 2016) thanks to its high ability to detect lineaments.

2.3.2. Principal Component Analysis (PCA)
The comparison of five types of enhancement techniques (mean value of all bands, PCA, Band Ratios (BR), the histogram equalization, and the high-pass filter) performed by (Walsh & Mynar, 1986) showed that PCA is efficient when used in the identification of lineaments. It is a statistical method, which is widely used in geological studies, exactly in the detection of lineaments. The PCA is a linear processing technique used to reduce multidimensional (multispectral) highly correlated data for effective geological interpretation (Bonn & Rochon, 1992).

The components resulting from the PCA allow the creation of colored compounds with a large difference in contrast between the objects in the field, which facilitate visual interpretations of the data. The colored PCA composition used in this work is generated by the first three components of the PCA (PC1, PC2 & PC3) (Fig. 4), and their statistical calculation reveals that the components PC1, PC2 & PC3 contain more than 89% of the information of the spectrals bands of the landsat 8 OLI image.

![Fig. 4. PCA (PC1, PC2 & PC3) result of the study area](image1)

![Fig. 5. Digital Elevation Model result](image2)
2.3.3. **DEM Acquisition and Shaded Relief Preparation**

For precise structural mapping and optimized results, obtained from the processing of the PCA data and the NIR of the OLI image, we used the GDEM ASTER Digital Elevation with a resolution of 30 m × 30 m (Fig. 5) to prepare eight shaded relief images with multiple lighting directions.

Additionally, the shading map derived from the DEM data contributes to the characterization of lineaments, by analyzing shaded pixels with neighboring pixels. The lighting gradient of the study area and the boundaries between shaded and unshaded areas can indicate the existence of lineaments (Masoud & Katsuaki, 2006a; Abarca, 2006; Saadi et al., 2011).

The first shadowed relief picture had a solar azimuth (sun angle) of 0°, and a solar elevation of 30°. An Ambient Light setting of 0.20 was used, which resulted in good contrast, and the other seven shaded relief images were generated with seven light contrasts in the orientations of 45°, 90°, 135°, 180°, 225°, 270° and 315° (Fig. 6).

The second step is to combine four shaded reliefs to create one shaded relief image. For this process, the combinations of the four shaded relief maps are treated using the GIS overlay technique, where the initial four shaded relief images are superposed to produce an image in various light directions (0°, 45°, 90° and 135°). Concerning the second superposition, it is intended to produce an image with different light directions (180°, 225°, 270° and 315°). Finally, these two images (Fig. 7) were used for automatic lineament extraction in the study area (Abdullah et al., 2010).

![Fig. 6. Eight shaded relief images derived from DEM showing different sun angle sun azimuth (0°, 45°, 90°, 135°, 180°, 225°, 270, and 315°) and a solar elevation of 30°. An ambient light setting of 0.20.](image-url)
2.3.4. Filtering

To identify the lineaments, we implemented spatial convolution filters on the previously cited approaches, specifically the directional filters (edge detection algorithms) of Sobel [33], which are applied in order to improve the identification of linear structures (Table 2). A 7x7 kernel network was used to detect and cover all lineaments that exist, the kernels scanned the image in all directions that lineaments can take, which are north-south (N-S), east-west (E-W), northeast-southwest (NE-SW), and northwest-southeast (NW-SE), in order to generate filtered images indicating the existing lineaments. The table (Table 3) presents the structuring of the cores used with their weight given in the study area.

**Table 2.** Sobel Filter values applied in all four directions

<table>
<thead>
<tr>
<th>Filter</th>
<th>N – S</th>
<th>NE – SW</th>
<th>E – W</th>
<th>NW – SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sobel</td>
<td>-1 -1 0 1 1 -1 -1 0 0 -1 -1 -1 -1 0 0 -1 -1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-1 1 0 1 1 -1 1 1 0 0 0 1 1 1 1 1 0 0 1 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-1 1 0 1 1 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-1 1 0 1 1 0 0 0 1 1 1 1 1 1 1 1 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 3.** Matrix of weighting coefficients of the 7x7 directional filter for Sobel

<table>
<thead>
<tr>
<th>7x7 Sobel 1</th>
<th>7x7 Sobel 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1 -2 -3 0 3 2 1 -1 -2 -3 -4 -3 -2 -1</td>
<td></td>
</tr>
<tr>
<td>-2 -3 -4 0 4 3 2 -2 -3 -4 -5 -4 -3 -2</td>
<td></td>
</tr>
<tr>
<td>-3 -4 -5 0 5 4 3 -3 -4 -5 -6 -5 -4 -3</td>
<td></td>
</tr>
<tr>
<td>-4 -5 -6 0 6 5 4 0 0 0 0 0 0 0</td>
<td></td>
</tr>
<tr>
<td>-3 -4 -5 0 5 4 3 3 4 5 6 5 4 3</td>
<td></td>
</tr>
<tr>
<td>-2 -3 -4 0 4 3 2 2 3 4 5 4 3 2</td>
<td></td>
</tr>
<tr>
<td>-1 -2 -3 0 3 2 1 1 2 3 4 3 2 1</td>
<td></td>
</tr>
</tbody>
</table>
From the resulting spatial filtering techniques and lineament identification processing, we can produce lineament mapping by automatically extracting the linear structures that appear on the filtered image results. These approaches have become more popular than manual approaches, which are complicated, time-consuming, and highly dependent on the quality of the analysis (Masoud & Katsuaki, 2006a). The approaches allow for better lineament distinction using the LINE lineament extraction algorithm in PCI's Geomatical software. The LINE module extracts lineaments from an image and translates these linear features into vector form using six optional parameters (RADI, GTHR, LTHR, FTHR, ATHR and DTHR) Table 4, Sarp briefly explains these parameters (Sarp, 2005).

Table 4. Parameters used for LINE module of the PCI Geomatica

<table>
<thead>
<tr>
<th>Spectral Bands</th>
<th>Suggested Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filter radius (Pixels)</td>
<td>5</td>
</tr>
<tr>
<td>Gradient threshold</td>
<td>75</td>
</tr>
<tr>
<td>Length threshold (Pixels)</td>
<td>10</td>
</tr>
<tr>
<td>Line fitting error threshold (Pixels)</td>
<td>2</td>
</tr>
<tr>
<td>Angular difference threshold (Degrees)</td>
<td>20</td>
</tr>
<tr>
<td>Linking Distance threshold (Pixels)</td>
<td>1</td>
</tr>
</tbody>
</table>

Remote sensing studies always require validation of the extracted data in order to eliminate redundant lineaments and to discriminate between tectonic and non-tectonic features. Therefore, the lineaments automatically extracted by each method were compared to other data sources such as geological maps, topographic images and high-resolution Google Earth images, in order to eliminate any lineaments of entropic origin that could be expressed as linear valleys, linear slope breaks or linear ridgelines (Jordan et al., 2005).

3. Results and Discussion

The statistical analysis of three types of data allows for determining the number of lineaments extracted from the NIR and the PCA, which are respectively 907 and 919 lineaments (Figs. 8C & 9C). While the number of lineaments extracted from the two shaded relief images is 314 and 279 lineaments respectively (Fig. 10C), which implies that the Landsat OLI image extracts more lineaments than the shaded relief method. The length-frequency plot shows that the length of the structural lineaments ranges between 0.9km and 5.3km for the NIR, in which the majority of the lineaments have a length between 1 and 2km, for the length of the structural lineaments extracted from the PCA is between 0.2 and 6.3km and for the lineaments of the two shaded relief images have a length of 0.1km to 9.3km for the first shaded image and 0.1km to 8.7km for the second shaded image. These results indicate that the Landsat OLI images extract the smallest structural lineaments, while the DEM image identifies the longest lineaments, which implies the complementarity between the three types of data used in this study.

For studying the distributions and orientations of the lineaments presented in the synthetic maps of the different mentioned methods (Figs. 8A, 9A & 10A), we used the rose diagram method, which represents the frequencies of the lineaments in a given degree range. By analyzing these rose diagrams, we can identify that the dominant orientation of the lineaments of all three methods is NE-SW. The main direction of the lineaments extracted from the NIR of the Landsat OLI image is oriented NE-SW (Fig. 8B), as well as the directional distribution of the PCA lineaments, it has a similar direction to that of the NIR in addition to an NNE-SSW direction (Fig. 9B), while the rose diagram of the two hills shade images has two oriented directions NE-SW, E-W and WNW-ESE (Figs. 9B & 10B). The resulting lineament maps were analyzed in terms of their density, also known as lineament length density, which is a widely used parameter, it provides information on the concentration of lineaments per unit area, and
it represents the sum of fracture lengths per unit area (Fig. 10). Through an analysis of the lineament density maps from Landsat OLI, PCA and DEM (Fig. 10), we can derive major directions detected by densities that are identical or similar to those deduced from the directional roses (NS-EW, NNE-SSW, NW-SE and WNW-ESE) with a dominance of the NE-SW direction.

**Fig. 8.** B. rose diagram of lineaments; C. length frequency diagram of lineaments.

**Fig. 9.** B. rose diagram of lineaments; C. length frequency diagram of lineaments.
Fig. 10. The density of the lineaments extracted from: A. The NIR of Landsat OLI image; B. PCA image; C & D. The Shaded Relief image

The resulting lineaments were compared with other pre-existing documents related to the regional geology of the study area. For example, the geological map revealed that the lineaments extracted automatically, by GIS and remote sensing, following the direction of the major faults indicated on the map in a dominant NE-SW direction. In addition, many Moroccan and international researchers have shown that the area was exhumed during the late-Hercynian and Atlas thrusts, which created extensional and compressional forces due to the influence of the Epeirogenic and Orogenic movements that succeeded each other from the Upper Paleozoic to the Quaternary that resulted in the creation of normal and strike-slip faults in various directions NE-SW, E-W, NNE-SSW, NW-SE and WNW-ESE.

The structural deformation in the area that has been processed by satellite imagery and DEM, highlights a major NE-SW constraint direction that corresponds to the traces of tectonic movements, collected especially in the western part of the area, and represented by normal faults of the Atlas Orogeny. As well as the directions from WNW-ESE to NW-SE correspond to the strike-slip faults also thanks to the manifestations of the Atlas phase, this direction is visible, especially in the hills shade image (Fig.10). While Hercynian tectonics is predominant in the basement with preferential directions NNE-SSW to E-W through intermediate directions, corresponding to the lineaments extracted from the PCA and hills shade image (Figs. 9 & 10).
As a result, this signifies a good correlation and similarity between the results obtained by using different satellite data and by applying automatic lineament extraction and the work already done in the Western High Atlas.

4. Conclusions

Remote sensing coupled with Geographic Information Systems is an essential element to know the structural deformation and the distribution of fractures, especially in areas that are enormous and difficult to access. The methodological approach of merging the three used methods (NIR of Landsat OLI NIR, PCA and DEM) allowed us to carry out a synthetic mapping with a maximum of structural lineaments (907 Lineaments were extracted from the NIR band, 919 from the PCA, and between 279 and 314 of the lineaments were detected from the two shaded relief images) associated with an average NE-SW to E-W trend, with the dominance of the NE-SW orientation. This distribution was checked and compared with existing geological work in the region, indicating many similarities and complementarities.

The territory covered by the study area is part of the Western High Atlas, which is the southernmost segment of the Western Moroccan Hercynian. It is considered a key region in the geology of Morocco, especially in the geodynamic evolution of the region, since it presented a continuous evolution from the Early Hercynian (NE-SW), Major Hercynian (NW-SE), Atlas (NE-SW), and finally Alpine (N-S). This study shows the effectiveness of remote sensing and GIS for structural mapping in complex areas, where lineaments are intricate to detect by conventional methods. The synthesis map is complete and reliable and can be used in the exploration of oil, groundwater and mineral deposits in the Western High Atlas.

References


