



## Contribution of remote sensing and geochemistry approaches to identify hydrogeological interconnections between Sminja and Oued Rmel Aquifer System (SORAS) (North-eastern Tunisia)

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### ABSTRACT

The Sminja–Oued Rmel aquifer system, located at Zaghouan region, is exploited for irrigation and meeting the drinking water demands of agglomerations. To identify the lateral communications between the Sminja and Oued Rmel aquifer system, two approaches were applied: geochemistry and remote sensing. The chemical analyses of waters of the two aquifers show a predominance of sodium and calcium cations and chloride and bicarbonate anions. An enrichment of sodium and chloride from upstream to downstream of each aquifer was found. A raise of sodium and chloride concentrations were founded from upstream to downstream for each aquifer. A similar chemical composition of the water samples located in the west part of Oued Rmel aquifer and waters of Sminja aquifer was identified. This proves, through mixture phenomenon, the importance of communication of waters of the Sminja to the Oued Rmel aquifer. The lineaments mapping was developed by processing Landsat ETM+ satellite data with several techniques (color composition, principal component analysis and filtering) and using computer softwares such as Envi, ArcGis and PCI Geomatica. The analysis of lineaments map pulled out a total of 13 hydraulic fractures which allow the hydrogeological interconnections between both aquifers. The statistical analysis of lineament patterns using directional rosettes and the lineament density map showed a predominance of ESE–WNW faults.

*Keywords:* Geochemistry; Hydrogeological interconnections; Remote sensing; Landsat ETM+; Sminja–Oued Rmel aquifer system

### 1. Introduction

In the past, water has always been regarded as an inexhaustible and renewable resource. Today, water crisis affects several countries of the world aggravated by climate conditions, increased demand, socio-economic development and demographic growth, especially for countries with a semi-arid to arid climate [1].

With only 1% of the world's renewable water resources, the Middle East and North African region is the most water scarce region in the world. Tunisia, by its geographical

situation between the Mediterranean and the Sahara, is influenced by two most different climates, one Mediterranean in the north and the other Saharan in the south, causing a significant spatial–temporal variation of water resources [2]. Indeed, annual average precipitation ranges from 100 mm in the extreme south to more than 1,500 mm in the extreme north of the country [3]. This rainfall gradient makes Tunisia a country with relatively few renewable water resources. The Sminja–Oued Rmel aquifer system is located about 50 km south-west of the city of Tunis, between 4016908 and 4037615 UTM of longitude East and 585451 and 623301 UTM of North latitude (Fig. 1).

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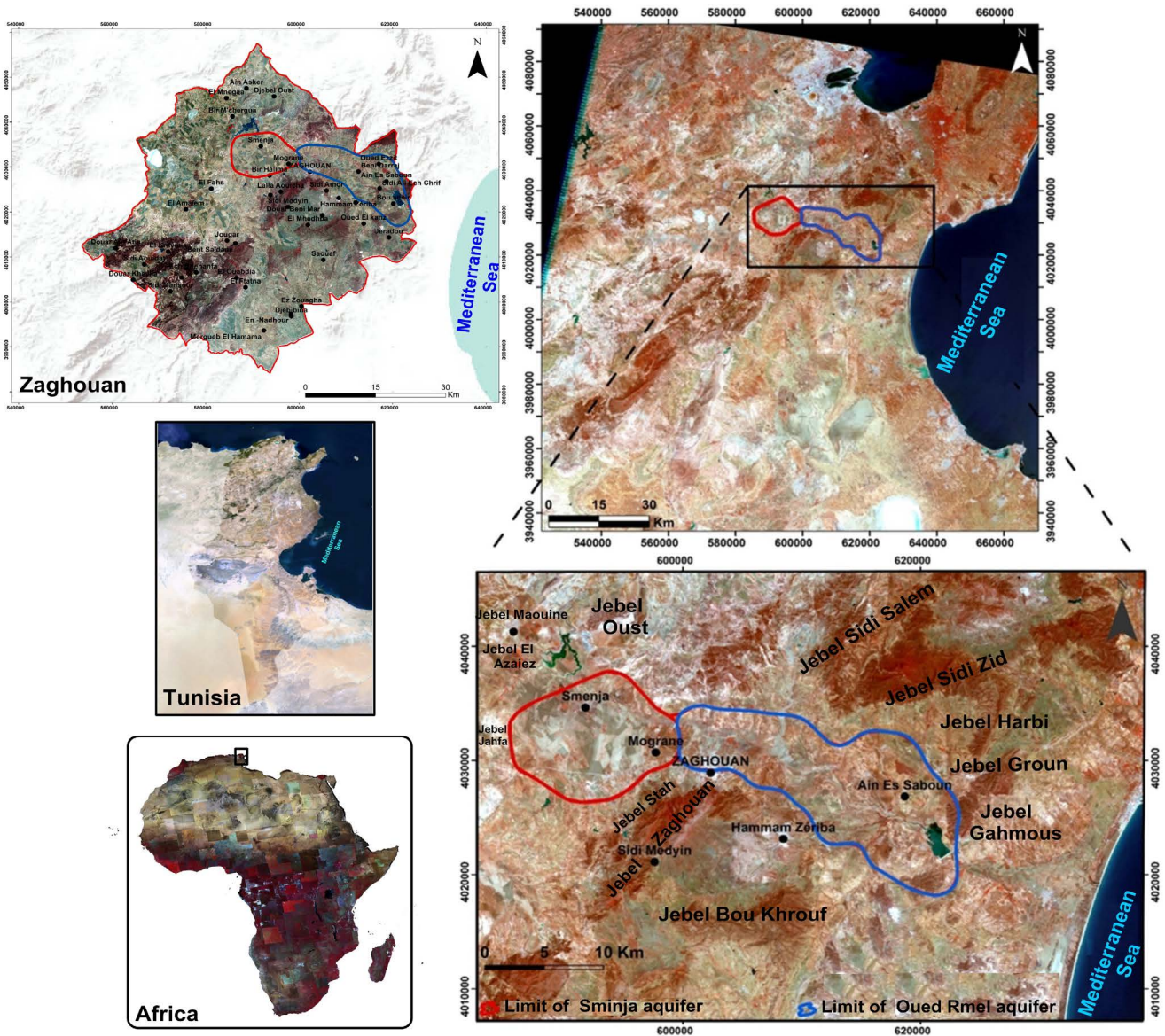


Fig. 1. Location map of the study area.

It is topographically bounded by Jebel Oust, Sidi Salem and Sidi Zid in the north, by Jebel Harbi, Groun and Gahmous in the East, by Jebel Zaghwan, Stah and Bou Khrouf in the South, and by Jebel El Azaiez, Maouine and Jahfa in the West [4].

The main goals of this work were to identify the potential corridors of groundwater flow between the Sminja and Oued Rmel aquifers and to compare the obtained results with geochemical characteristics.

## 2. Materials and methods

Geographic information system (GIS) combined with remote sensing computer software and geochemistry approach can provide real-time information about water resources chemistry of Sminja–Oued Rmel aquifer, to identify

the mixing phenomena and to confirm the lateral hydraulic communication between the two aquifers.

### 2.1. Geochemical approach

The piper diagram is used for better understanding of waters geochemistry of Sminja–Oued Rmel aquifers, as well, to identify subsequently the similarities between facies of both aquifers. The geochemical facies of waters of the two aquifers were settled by the use of Aquachem software and piper diagram.

To demonstrate the chemical link between the water aquifers, the mixing phenomena were studied, using PHREEQC software.

This approach based on the uses of major elements concentrations of two aquifers as input and thus to evaluate the theoretical mixing concentrations.

The binary plots (Fig. 3b) show the concentrations distribution of major elements resulted from the mixing of saline water of Sminja aquifer with the softer water of Oued Rmel aquifer.

### 2.2. Remote sensing approach and steps for processing satellite imagery

The potential corridors of groundwater flow between aquifers were founded by applying GIS and high-resolution multi-spectral remote sensing on Landsat 7 ETM+ images (Fig. 2).

## 3. Results and discussion

### 3.1. Hydrogeochemical water facies

The Fig. 3a shows two types of facies predominance of waters chemical compositions on piper diagram of both aquifers. A gradual shift of facies from the upstream mixed facies (Na–Ca–Cl–SO<sub>4</sub>) to the downstream sodium chloride facies (Na–Cl) of Sminja aquifer was observed.

However, the facies path of Oued Rmel aquifer from its upstream (West) to downstream (East) is described

as following (Na–Ca–Cl–HCO<sub>3</sub>), (Na–Ca–Cl–SO<sub>4</sub>) and chloride–sodium, respectively.

Chloride represents the most abundant ion in the anionic composition of waters of Sminja aquifer (61%) and the Oued Rmel aquifer (55%), whereas sodium is the dominant pole in the cationic composition of the waters of both aquifers with percentages of 60%.

The diagrams of Cl<sup>-</sup> as function of Na<sup>+</sup>, Mg<sup>2+</sup>, Ca<sup>2+</sup> and K<sup>+</sup> (Fig. 3b) obviously show that some water samples of Oued Rmel aquifer, such as FR1 (Hmida ben Ali), FR2 (Hamadi el Kefia), PR1 (Faycel Kedher), PR2 (Pépinière Zaghouan), and PR3 (Hatem el Soufi) are narrowly dispersed on the theoretical mixing line. Therefore, the water chemical ties between (FR1, FR2, PR1, PR2 and PR3) boreholes and other boreholes in the Sminja aquifer are confirmed.

This chemical composition link was argued by a lateral communication at some location between the Sminja and Oued Rmel aquifers.

The waters of the boreholes located at the east and south of this aquifer show different chemical compositions from the Sminja aquifer. In order to confirm these results, PHREEQC software was used to define the contribution percentages of the Sminja to the Oued Rmel aquifer.

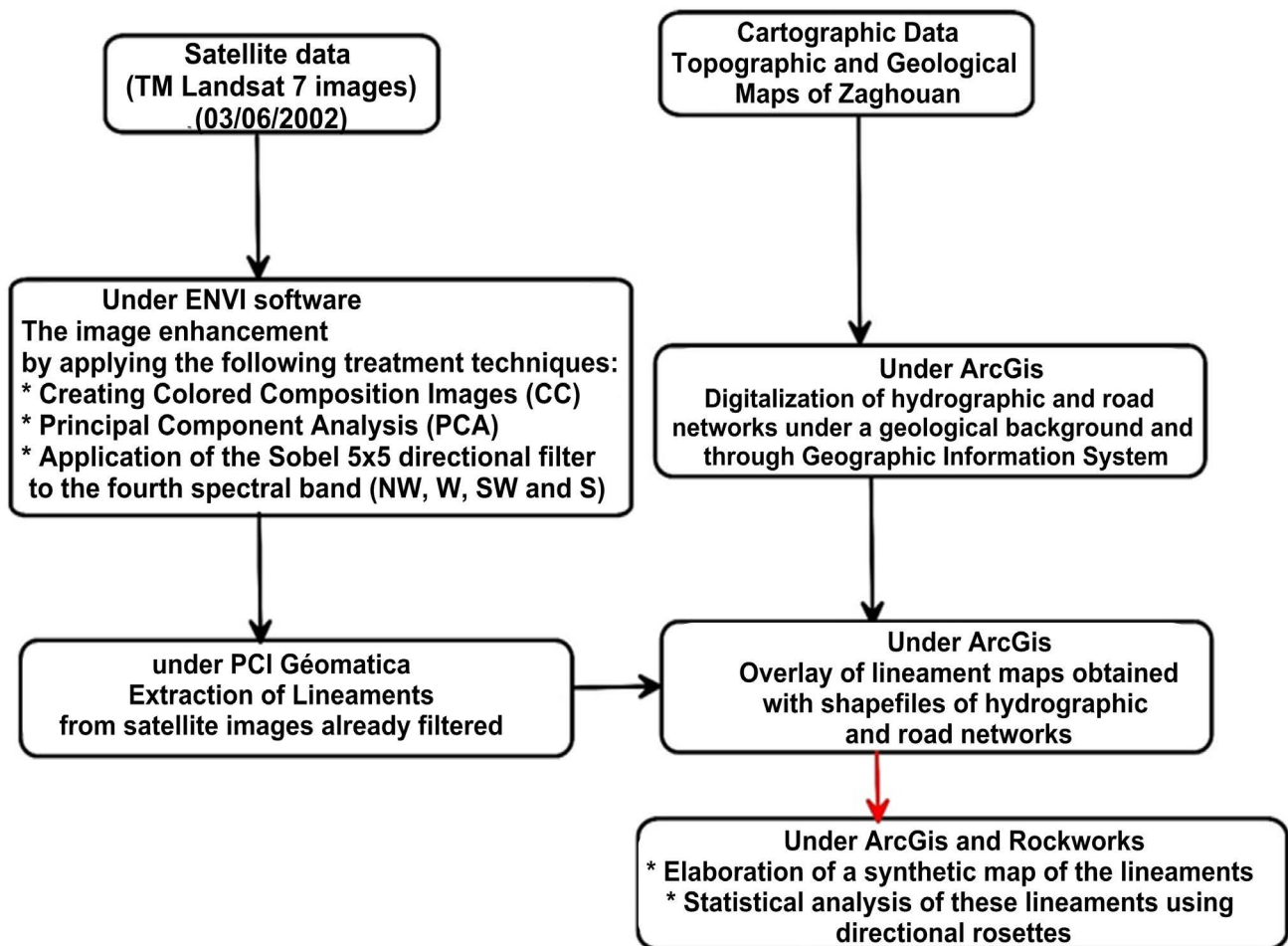


Fig. 2. Chart of the working method adopted to extract the lineaments from the satellite images.



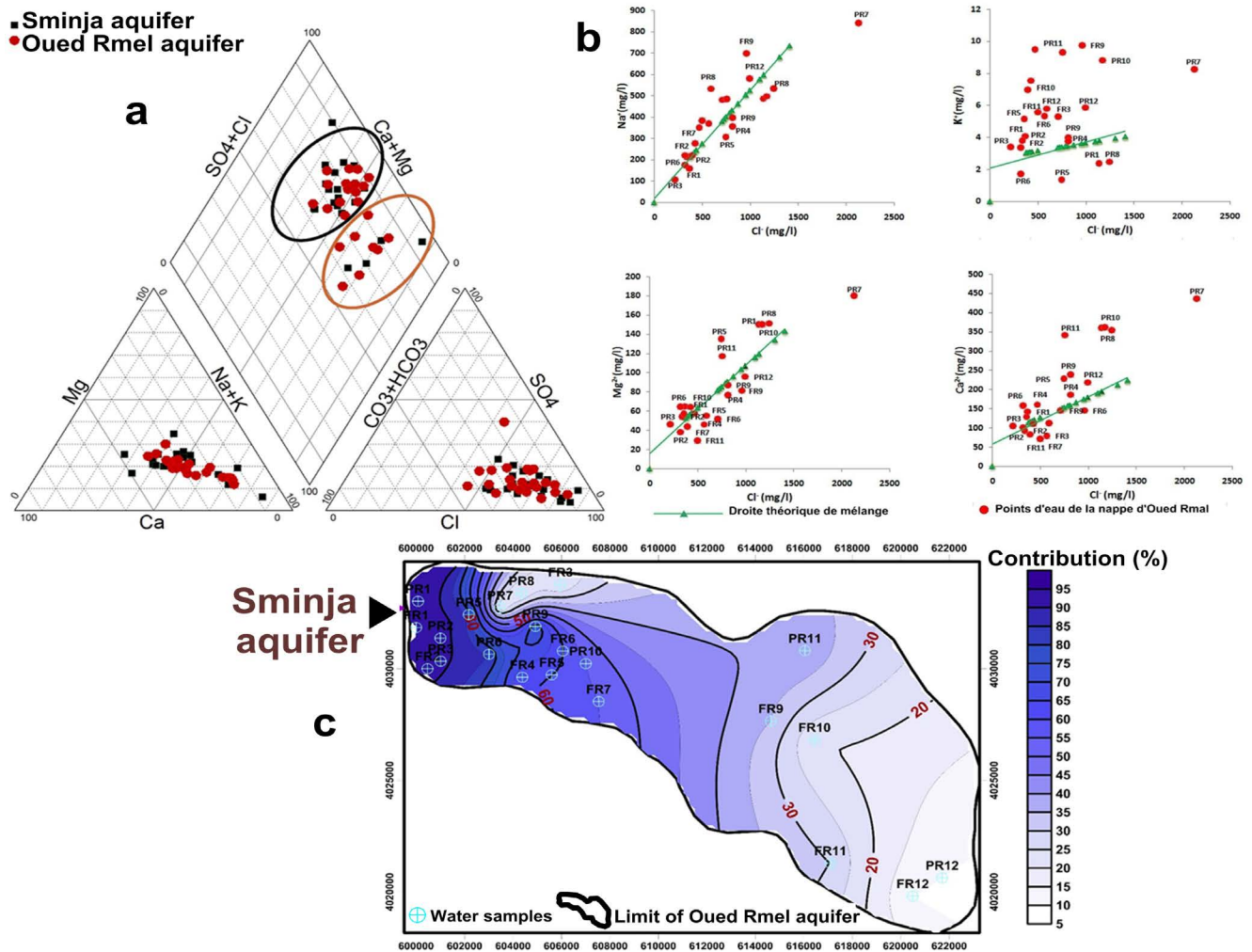


Fig. 3. (a) Chemical facies of Sminja–Oued Rmel aquifers, (b) relative position of the Oued Rmel aquifer wells to the theoretical mixing line and (c) percentages estimation of water Sminja feeding to Oued Rmel aquifer.

The Fig. 3c proves that the western part of the Oued Rmel aquifer is the most influenced zone by water driven from the Sminja aquifer. In addition, the highest percentage of water exchange was identified in the western part and the lowest contribution percentages at the southern part.

### 3.2. Treatment under ENVI

#### 3.2.1. Creating colored composition images (CC)

In a total of seven bands in the Landsat TM images, only bands 4, 2 and 1 were allocated to the red, green and blue channels, giving a colored composition (Fig. 4a) that provides good discrimination between the ground, vegetation and bodies of water.

#### 3.2.2. Principal component analysis

The principal component analysis (PCA) method was applied to the six Landsat 7 TM spectral bands. In our study, thermal infrared bands were excluded which is the case

of band 6. This processing is carried out by the “Principal Components” module of the ENVI software.

Statistical calculation of main components and PCA histogram show that mostly full information are visible on the first four components, which represent 99.89 of the total variance of all six bands (Fig. 4b). The image obtained with CC of the 4-2-1 bands as well as the image resulting from the PCA was used in conjunction with the filtered images to localize and to extract the lineaments (Fig. 4c).

#### 3.2.3. Enhancement of lineaments by filtering

After localization and extraction of lineaments, the technique of lineament enhancement by filtering was applied to improve the visual quality of image and to optimize elements extraction with similar characteristics by using a defined spatial frequency and directional Sobel filters (Fig. 5a) [5].

The area of aquifer subject of study is 312 km<sup>2</sup>. Due to the size of structures, a convolution window of filter 5 × 5 was applied to detect major lineaments greater than 75 m (Fig. 5b).

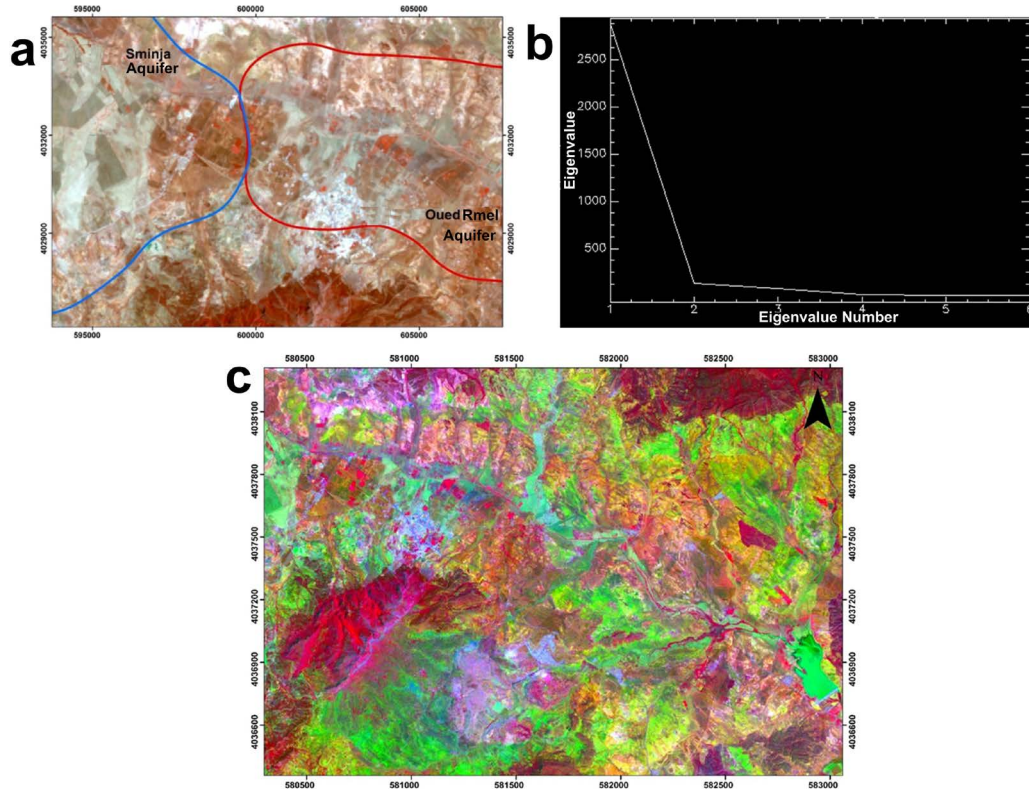


Fig. 4. (a) 4-2-1 bands colored compound image of the study area, (b) histogram of Landsat 7 ETM spectral bands and (c) RGB image developed from CP4, CP2 and CP1 components.

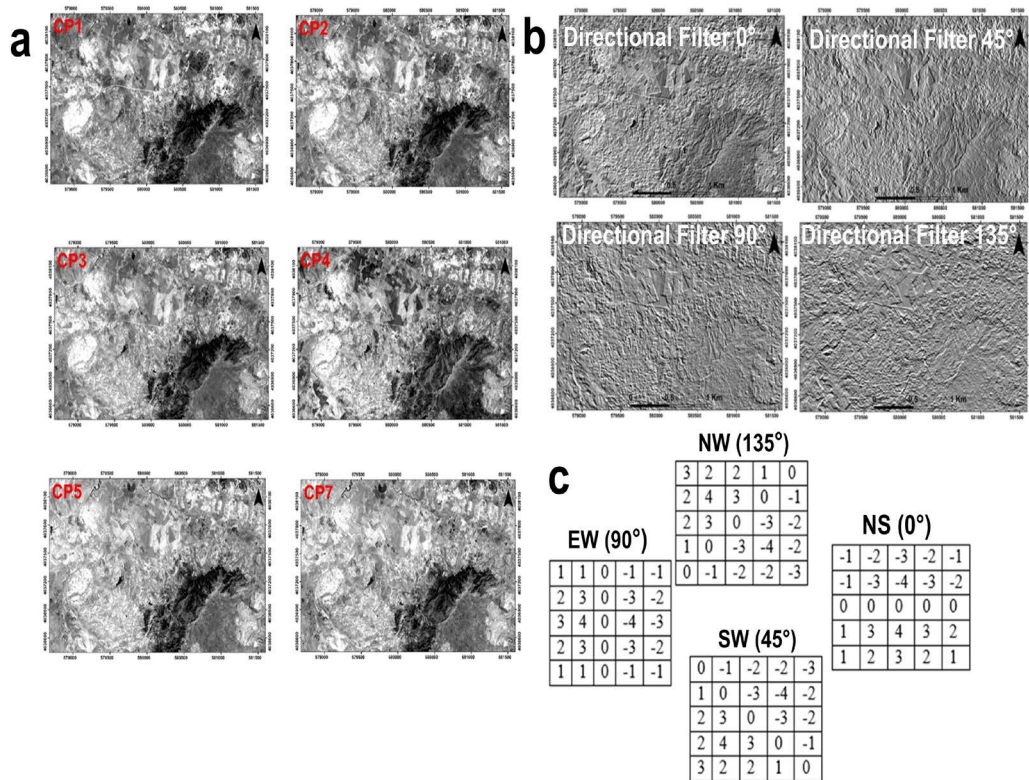


Fig. 5. (a) Calculated components from ETM six spectral bands (TM1, 2, 3, 4, 5 and 7), (b) 5 by 5 Sobel filter matrices and (c) derivative images from NW, EW, SW and NS directional filters Sobel.



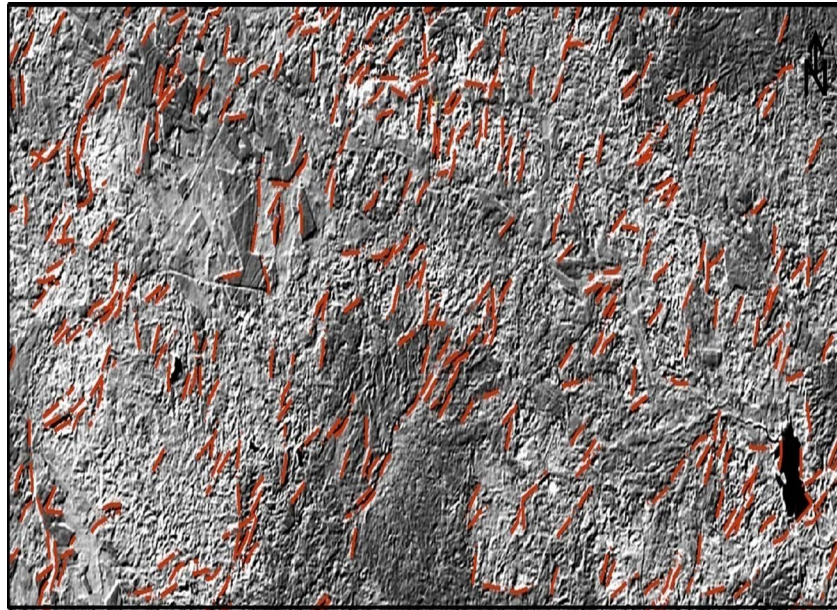


Fig. 6. Extraction of lineaments under PCI Géomatica.

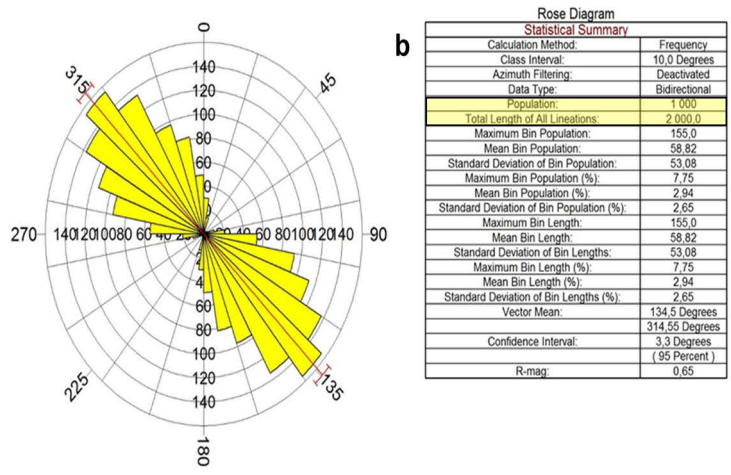
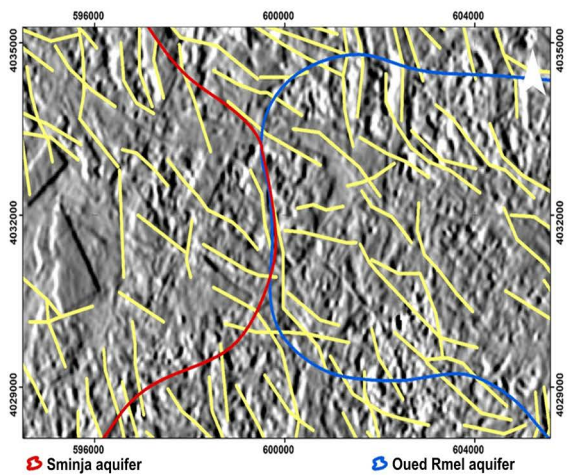
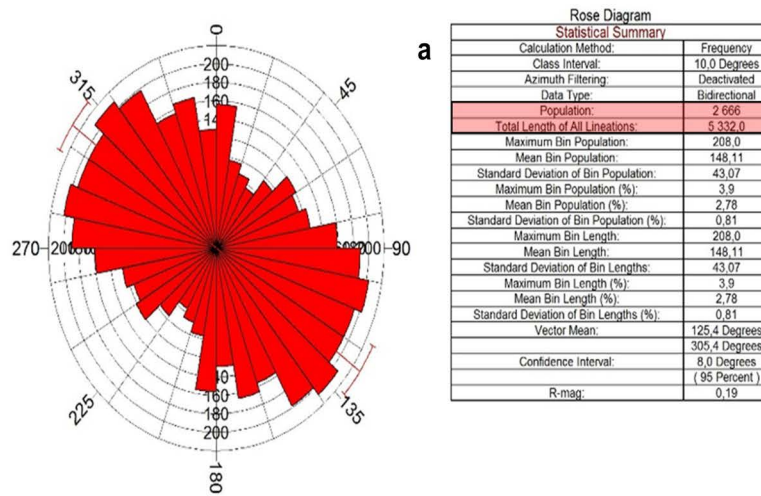


Fig. 7. (a) Rose diagram lineaments frequencies and (b) rose diagram of the major direction.

The filtering is applied on band 4 image which is in the near infrared spectral domain that allows the identification of important structural details [6].

After filtering, four derivative images (Fig. 5c) were generated from the four directional Sobel filters (NW, EW, SW and NS).

### 3.2.4. Mapping of lineaments

To eliminate anthropogenic structures, the already vectorized road and hydrographic networks worked out under ArcGis, were superposed on the different processed images across a GIS [7].

The synthesis map was settled by the superposition of the four maps of the lineaments obtained from NW, EW, SW and NS directions. To avoid repetition of the segments on this synthesis map, the repeated lineaments were eliminated.

### 3.2.5. Extraction of lineaments under PCI Géomatica

The lineaments were extracted by performing an auxiliary processing on the four filtered images of the band 4 with PCI Géomatica (Fig. 6).

### 3.3. Statistical analysis of lineaments

This technique consists of producing directional rosettes proportional to the cumulative length of lineaments classified by 20° orientation (Fig. 7a).

The Rockworks software combined with neo-data resulting from the GIS calculation was used to generate directional roses defined above.

The lineaments map shows the set of fractures resulted from South filtering (0°). It has a total of 817 lineaments expended on length of 1,634 m in total.

The SW filtering applied on the lineament has a heterogeneous fracture distribution which counts 1,000 lineaments on a total length of 2,000 m (Fig. 7b).

The frequency diagram combined with this map shows a predominance of EW lineaments trend. It had been noted that the EW lineaments trend at Sminja aquifer has the highest density lineament zone (Figs. 8a and b), in contrast to

Oued Rmel area. Most of accidents are located at Sminja aquifer.

Table 1 describes the characteristics of the different lineaments maps. The lineaments statistical analysis (Table 1) indicates a preferential SW direction.

The lineaments map coupled with lineaments directional rose extracted from SW filter shows that the main sub-meridian direction is NS.

The lineaments synthesis map holds 2,666 lineaments in total splitted on total length of 5,332 m [8].

The Table 2 shows the Rockworks calculated results applied on synthesis map displaying the lineament orientation distribution. It illustrates the major four lineaments families, which are SE-NW, ESE-WNW, SSE-NNW and ENE-WSW with correspondent of total lineaments percentage of 22.23%, 21.75%, 17.52% and 15.49%, respectively.

Table 1  
Characteristics of the different lineaments maps

Map of Lineaments	Number of Lineaments	Total Length of Lineaments (m)
North West	383	766
South West	1,000	2,000
South	817	1,634
West	468	936
Synthesis Map	2,666	5,332

Table 2  
Lineament orientation percentages extracted by Rockworks software [8]

Angle	Direction	Number of lineaments	Percentages %
00–30	NNE-SSW	327	12,14
30–60	NE-SW	293	10,87
60–90	ENE-WSW	417	15,49
90–120	ESE-WNW	586	21,75
120–150	SE-NW	599	22,23
150–180	SSE-NNW	472	17,52

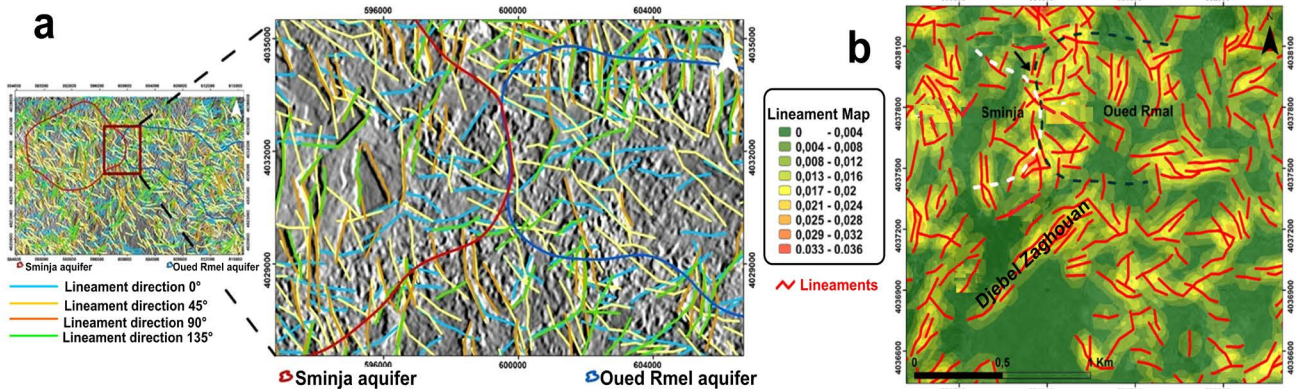


Fig. 8. (a) Lineament map synthesis and (b) map distribution and lineaments density of the study area.



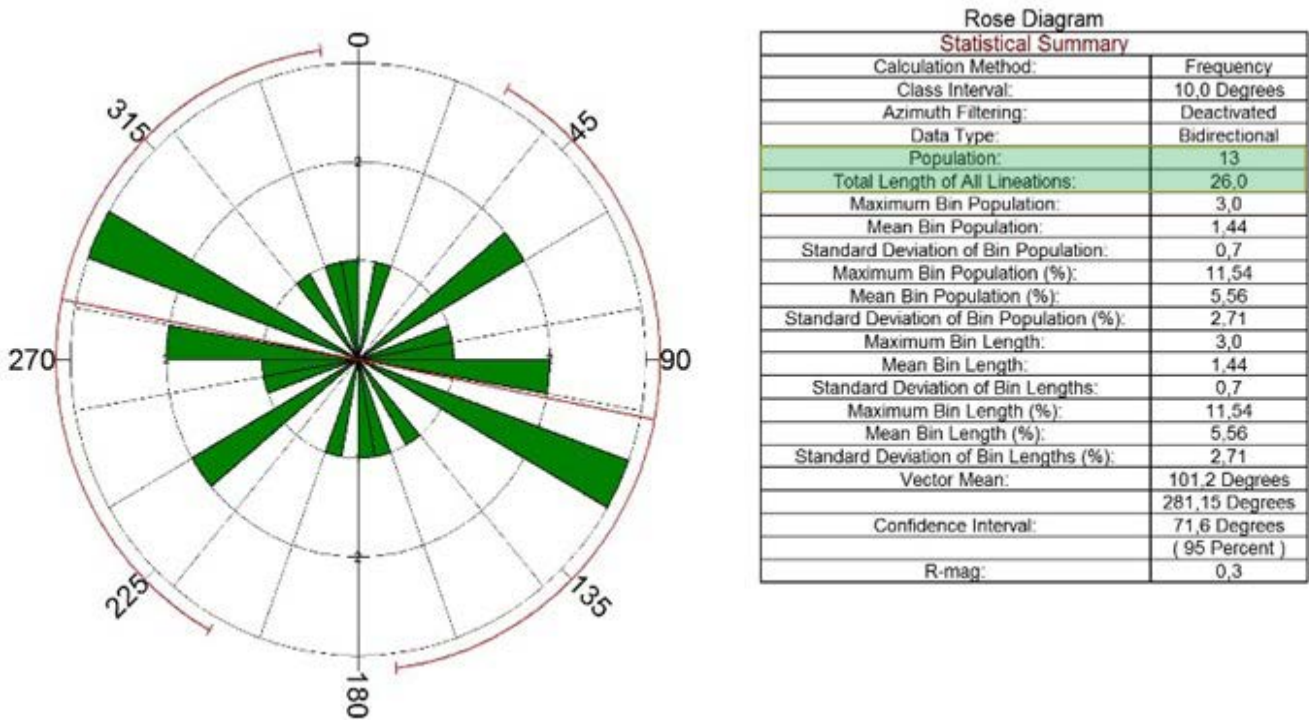


Fig. 9. Structural synthesis map of the study area.

Application of different processing techniques to satellite imagery Landsat 7 ETM+ figured out a total of 13 fractures on 26 m total length insuring the lateral communication faults family from Sminja to Oued Rmel aquifer (Fig. 9).

#### 4. Conclusions

Several approaches such as geochemistry and remote sensing processing were applied to identify the hydraulic lateral communication between Sminja and Oued Rmel aquifers.

The chemical composition link between the water aquifers had been proven through the mixing phenomena using PHREEQC software.

The chemical analysis applied to the water points located at the west part of the Oued Rmel aquifer shows similar chemical composition compared with the waters of Sminja aquifer. It had been proved that the western part of the Oued Rmel aquifer is the most influenced zone by water driven from the Sminja aquifer. Thus Sminja aquifer feeds Oued Rmel aquifer. Moreover, the water mixing line was plotted and the contribution percentage of Sminja to Oued Rmel aquifer was calculated, showing that Sminja aquifer contributes with around 95% of water resource exchange in the western part of Oued Rmel aquifer.

The Landsat ETM+ satellite images were processed with several techniques such as (color composition, main component analysis and filtering). It had been demonstrated that the result from the geochemical analysis and the result from the lineaments maps are in concordance.

A total of 13 fractures that provide the hydraulic lateral communication were identified.

The statistical lineaments analysis, as well as the directional roses and the lineament density map, was developed showing a predominance of ESE-WNW faults. Finally, the remote sensing result driven from the Landsat ETM+ satellite images combined with the geochemistry study confirmed that the lateral communications between the two aquifers is essentially ensured by the faults.

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