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Research article

Automatic extraction of lineaments from Landsat Etm+ images and their structural interpretation: Case Study in Nefza region (North West of Tunisia)

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Abstract

The lineaments are linear or curvilinear discontinuities in direct connection with the faults and the composite fractures. Lineament analysis constitutes an interesting approach in the geological mapping and mineral exploration.
In our study, various types of techniques to extract lineaments were applied to a panchromatic band of Landsat 7 ETM + image covering the Nefza mining district in the North West of Tunisia.
In the first step, four derived images were generated from four Sobel directional filters in all possible directions (N-S, E-W, NE-SW and NW-SE). These filters increase contrast in the image and allowed mapping a larger number of lineaments.
In the second step, the lineaments mapping was performed by using the Line module of PCI Geomatica. This will allow us an automatic extraction of lineaments.
The next step is the superposition of the lineaments maps obtained in different directions to create a synthesis lineaments map.
The result of this study show a positive correlation between structural geology (faulting, lineament, warping) and the dominant extracted lineament orientations. The highest densities obtained are oriented NE-SW, N-S and E-W, with the predominance of the first direction.

Key words: Lineaments extraction, Satellite images, Nefza, Tunisia.

1. Introduction

The availability of high resolution multispectral data and the ability of digital image processing techniques to generate enhanced images have expanded the remote sensing potential of geological lineaments extraction with greater accuracy (Drury, 1987).
Linear features on the earth surface have been a theme of study for geologists for many years, from the early years of the last century (Hobbs, 1904) up to now.

Several approaches have already been used in numerous studies in the world (Bonn et Rochon, 1992; Yésou et al, 1993; Savané, 1997; Kouamé, 1999; Jourda, 2005).
There are a variety of computer tools that can facilitate the interpretation of lineaments. Some even allow the automatic extraction of lineaments, using contrast-detection algorithms within an image. Abdullah et al., 2010 uses software PCI Geomatica with module LINE, which is used for extraction of linear features from raster images. Mallast et al., (2011) uses software ERDAS Imagine modules and PCI Geomatica. Argialas and Mavrantza on 2004 uses optimized Hough Transform method. Pinto et al., (2013) uses Hough Transform and software LESSA.
The extraction of geological lineaments from remote sensing data can be grouped into at least three approaches: manual extraction (Jordan and Schott, 2005); semi-automatic extraction (Lim et al., 2001, Jourda et al., 2006) et finally the automatic extraction (Anwar et al., 2013; Rayan, 2013). In manual and semi-automatic approaches, the lineament extraction is influenced by the experience of the interpreter, whereas the automatic extraction depends mainly on the performance of the application and of the information in the image used (Al Dossary and Marfurt, 2007).
The main objective of this work is to evaluate the results of automatic extraction of lineaments from

Landsat 7 image Etm + of the Nefza region located in the northwest of Tunisia (figure 1). Our approach is based on the automatic extraction of tectonic lineaments from the panchromatic band.

The use of Landsat 7 image and especially the panchromatic band, characterized by a resolution of 15m, for mapping lineaments is proving to be a highly satisfactory tool (Safaa et al., 2014).

However, the study and the mapping of geological lineaments, sources of information on the structural evolution of the region, poses a real problem because of the sporadic distribution of rocky outcrops, vegetation cover which covers, subtle variations in topography… Treatment of these images by appropriate techniques is therefore necessary to enhance their visibility.

The selection of appropriate parameters for automatic lineaments extraction with the PCI Geomatica Line module allows drawing the lineament map of the area. This map will be the subject of a spatial characterization using GIS. The comparison with results obtained in previous work related to the geology of the region contributes to evaluate the methodology.

2. Material and methods

2.1. Study area

The investigated area (figure 1) is located in the North East of Tunisia and enclosed between latitudes 8°48′08’’E and 9°10′35’’E and longitudes 36°53’34’’N and 37°05′30’’N, covering an area of 513,8 sq. km. The area enjoys sub-humid climate with 900 mm average annual rainfall.

The geologic map of Nefza district covered a party of the Maghrebide belt running E–W in the Western Mediterranean. It resulted from the collision between the African plate (Gondwana supercontinent) and the Meso-Mediterranean micro-plate called derived from the European continent during the Neo-Tethysian oceanic aperture in the Early Jurassic.

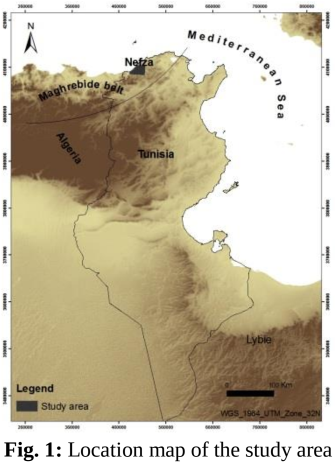


Fig. 1: Location map of the study area

The structural history of this region was generated according to three main steps (Rouvier, 1977):

- In the late Cretaceous period, the subduction of the Tethyan oceanic strip, which separated Gondwana from Alkapeca resulted in a flysch accretion prism “Kabylian flyschs” in the Eastern Maghrebides;
- Docking of the Alkapeca domain (Middle Eocene–Early Oligocene) with the Africa margin, altogether deformed (Bouillin, 1977);
- The Alpine phase (Latest Burdigalian–Early Serravallian) resulted from the collision between the dismembered Alkapeca and Africa domains.

Also, the geology of the region is characterized by several structural features that are usually associated with the phenomena responsible for the development of polymetallic mineralization, well as the transfer and dispersion on the surface of various geochemical elements.

During Neogene, when the Nefza magmatism emplaced, there was an alternation of oblique compressive regime and extension regime, which is typical of the postcollisional period. Most important, during the Serravallian and the Tortonian periods, the northern African realm was affected by a very oblique compressive regime (Benaouali et al., 2006), and experienced short-lived returns to extensional conditions during the Messinian and Pliocene periods.

Since then, the Africa– Europe convergence rate has been very low (0.5 cm.a−1) and the plate boundary is still located at the front of the Tellian Zone (Jolivet, 2008), with some folding just to the north of the coastline.

In the Northern Tunisian Tell region, studied here, the sedimentary substrate comprises the Ed Diss thrust sheet (Upper Cretaceous to Eocene) overlain by the Numidian nappe (Hurtrez and al., 1999). The latter consists of a thick (≥1000 m) series of siliciclastic flysch (Numidian flysch), Oligocene to Lower Miocene (Burdigalian).

The geological and the complex tectonic setting of this region, determines the increased tectonic activity, making it an ideal study region for testing the automatic lineament extraction methodology.

2.1. Methodology

A lineament is a mappable linear or curvilinear feature of a surface whose parts align in a straight or slightly curving relationship. They may be an expression of a fault or other line weakness (Hung et al., 2005).

Satellite remotely sensed data has been widely used as source of information for geologists to map lineaments.The satellite Landsat 7 ETM + of the study object region were uploaded from the USGS Earth

Explorer website http://earthexplorer.usgs.gov. These images were taken in the dry season and with without any cloud cover. Their characteristics are as follows: path/row: 192/34; date: 12/05/2009; file type: GEOTIFF; projection: UTM, zone 32 north; ellipsoid: WGS-84.

According to literature there are two common methods for the extraction of lineaments from satellite images: 1. Visual extraction: At which the user first starts by some image processing techniques to make edge enhancements, using the directional and non-directional filters then the lineaments are digitized manually by the user. Interpreter personal skills and experience will condition the reproducibility of the final results 2. Automatic extraction: various computer-aided methods for lineament extraction have been proposed. Use of such functions is easy and fast. They also offer a high degree of reproducibility in contrast to classic subjective manual processes (Mallast et al., 2011).

Most methods are based on edge filtering techniques. The most widely used software for the automatic lineament extraction is the LINE module of the PCI Geomatica.

We have uploaded a total of 9 images (band 1, 2, 3, 4, 5, 6-1, 6-2, 7 and 8). The panchromatic band was with a resolution of 15 m. In our methodological approach (figure 2) lineaments were automatically extracted from these bands with the LINE module of PCI Geomatica. However, the function includes several parameters that must be added simultaneously without possibility to visualize the impact of each of them separately.

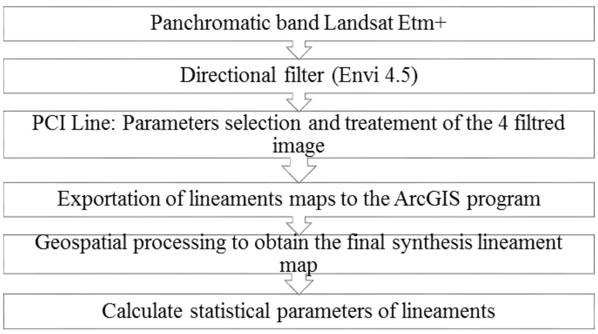


Fig. 2: Flowchart shows steps lineaments extraction and analysis

The directional filters induce an optical effect of shadow focused on the image like it were illuminated by oblique light. This type of filter was used in order to get a high accuracy in extraction (Marion, 1987). Directional filters are applied to image using a convolution process by mean of constructing a window normally with a (3×3) pixel box of Sobel- kernels filters (table 1). The directional nature of Sobel kernels generates an effective and faster way to evaluate lineaments in four principal directions (Suzen et al., 1998). Four filtered images have been produced by Envi 4.5 software related to the directions N-S, E-W, NE-SW and NW-SE, which are used as an inputs images for auto extraction methods.

Table 1: Sobel - kernels in four principle directions

N-S	NE-SW	E-W	NW-SE
-1 0 1	-2 -1 0	-1 -2 -1	0 1 2
-2 0 2	-1 0 1	0 0 0	-1 0 1
-1 0 1	0 1 2	1 2 1	-2 -1 0

The automated lineament extraction in this study is performed by the LINE module of Geomatica software. LINE module of Geomatica extracts linear features from an image and records the polylines in vector segments by using six parameters. The description of six parameters used in the algorithm is as follows (Table 2):

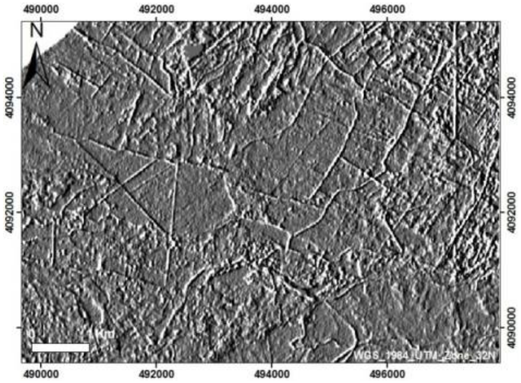
Table 2: Parameters used for PCI Line module

Parameter	Signification	Range and unit
RADI	Filter radius. It specifies the radius of the edge detection filter (Filter de Canny).	0 – 8192 (pixel)
GTHR	Gradient threshold. It specifies the threshold for the minimum gradient level for an edge pixel to obtain a binary image (Filter de Canny).	0 - 255
LTHR	Length threshold: It specifies the minimum length of curve to be considered as lineament	0 – 8192 (pixel)
FTHR	Line fitting error threshold: It specifies the maximum error (in pixels) allowed in fitting a polyline to a pixel curve.	0 – 8192 (pixel)
ATHR	Angular difference threshold: It is the maximum angle between two vectors for them to be linked.	0 - 90
DTHR	Linking distance threshold: It specifies the minimum distance between the end points of two vectors for them to be linked.	0 – 8192 (pixel)

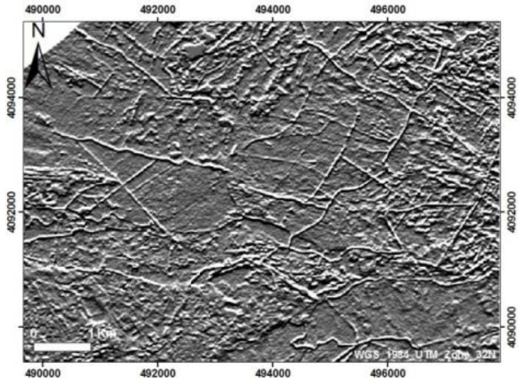
3. Results and discussion

In our study, enhancement of lineaments has been made from directional filters using Sobel operator. The convolution filter window 3 by 3 was used in order to detect the smallest length lineament. A subset of directional filtering images is shown in figure 3.

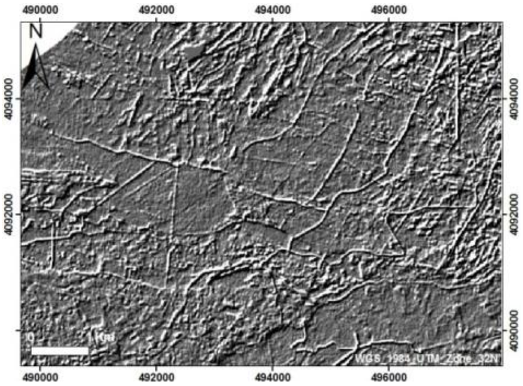
In order to extract the discontinuities resembling to the geological lineaments in the study area, the necessary



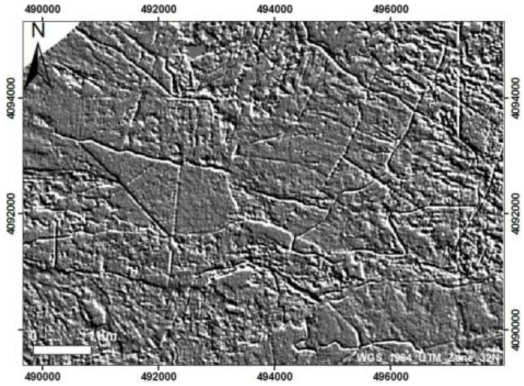
N-S filtered image



E-W filtered image



NE-SW filtered image



NW-SE filtered image

Fig. 3: Four subset filtered images derived from panchromatic band of Landsat 7 Etm+

and appropriate parameters for the Line Module PCI Geomatica were used.

The lineament extraction algorithm of PCI Geomatica software consists of edge detection, thresholding and curve extraction steps. Suggested settings values was selected from several setting tests. The threshold values are shown in table 3.

Table 3: Suggested parameters values

Parameters	Values
RADI	10
GTHR	100
LTHR	30
FTHR	3
ATHR	30
DTHR	20

The superposition of the four maps of lineaments obtained from the four filtered images allows creating a synthetic map of lineaments. Lineaments repeated more thanes once are eliminated to avoid repeating segments in the synthesis map. Singhal and Gupta (2010) noted that the automated methods generate many insignificant lineaments. So, the lineaments derived from human activities, hydrographic network and meaningless lineaments were eliminated using GIS tools. The lineament map obtained by automatic extraction from panchromatic band Landsat Etm+ is shown in figure 4.

The extracted lineaments are analyzed in order to extract information related to length, density and orientation analysis. Generally the frequency of automatic extracted lineaments is greater more than number of lineaments in the fault map of the study area.

The most important factor for this is that the lineaments in the automated one are shorter in length compared with the length of fault lines.

This technique identified the highest number of lineaments and the highest total length of lineaments compared with the number and the total length of faults in the study area.

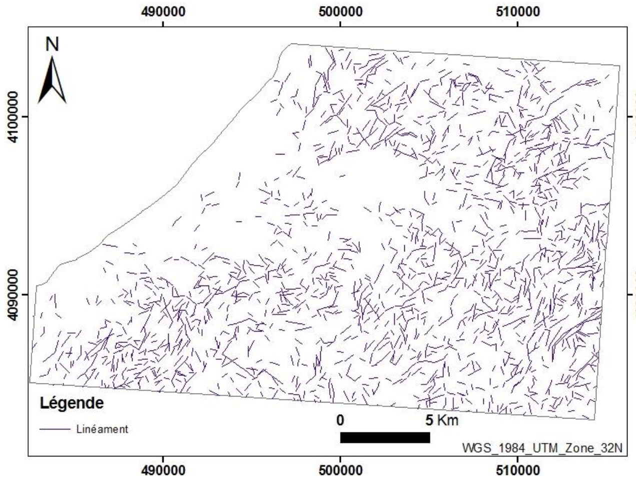


Fig. 4: Automatical extraction lineament map

A comparison between fault map of the study area and the lineaments extracted from enhanced Landsat images in terms of number of lineaments and the total length of lineaments is shown in table 4.

Table 4: Basic statistics of automatic lineaments maps and fault map

	Extracted lineaments	**Fault map**
Number	1617	817
Minimum length (Km)	0,26	0,27
Maximum length (Km)	2,5	4,154
Mean length (km)	0,51	0,538
Total length (km)	804	439

The density analysis calculates the frequency of the lineaments per unit area (Hung et al., 2005), and then produce a map showing concentrations of the lineaments over unit area. In this study, the lineament density is created by spatial analyst tool in (ArcGis 9.3) program. Lineaments density map of the overall lineaments is produced and shows in figure 5 and figure 6.

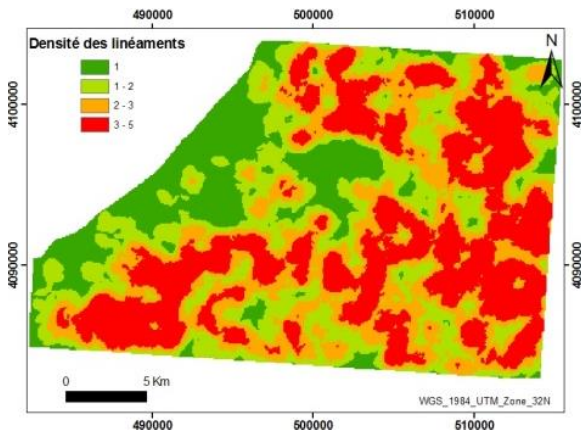


Fig. 5: Density of automatically extracted lineament

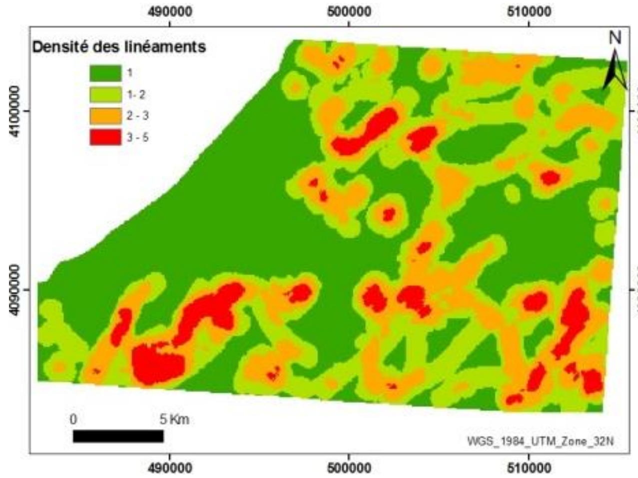


Fig. 6: Density fault map (Sedrette et al., 2015)

Lineaments orientations are usually analyzed by rose diagram in all researches which are dealing with these structures. A rose diagram tool from the (Rock works 14) was used to derive lineament directions. The conventional method consists in producing directional rosettes lineaments classes by 10° orientation.

As shown in figure 7, it has been noticed that the maximum number of lineaments are in the NE-SW direction. The second major trends of lineaments in the study area are respectively, N-S, E-W and NW-SE.

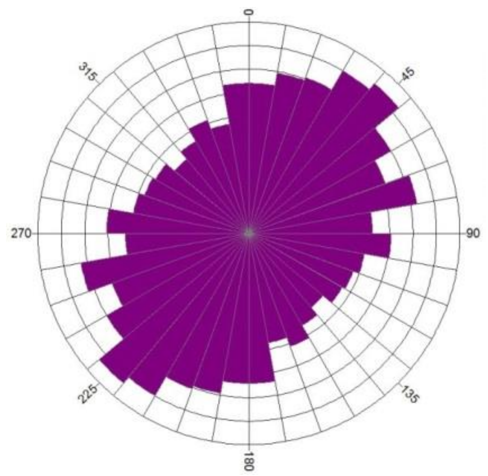


Fig. 7: Rose diagram for automatically extracted lineaments

Indeed, the statistical analysis of the structural lineament layer extracted from the Nefza geologic map (Sedrette and al., 2015) reveals that the directions of classes N60, N40 and NS are the major directions of the lineament distribution. The secondary directions are, in ascending order, the EW and NW-SE classes. So, this result indicates a positive correlation between structural geology (faulting, lineament, warping) and the dominant extracted lineament orientations.

The NE-SW direction, ancient and remobilized during the alpine and atlas stages, corresponds to the Cap

Serrat-Ghare Dimaou accident direction crossing the Nefza region. This accident is often the headquarters of Triassic extrusions and magmatic rocks usually accompanied by the establishment of several lead-zinc mineral deposits.

The both NS and NW-SE fracturing directions, although it is old, are the most recent tectonic remobilization which affected all Tunisia, this tectonic is known as post-Villafranchian stage (Zargouni, 1974; Zargouni et al., 1981; Ben ayed, 1986 and Vilalley et al., 1994).

According to Rekiss (2007) works, the EW lineament direction follows up the majority of magmatic outcrop border. This EW direction active during Eocene and Cretaceous times, have been rejuvenated at the end of the Neogene period and during Quaternary in a relay pattern system associated with compressive and extensive deformations according to the alternation of extension and compression phases.

5. Conclusion

In this paper, an attempt has been made for mapping lineaments and knowledgebase preparation using geomatics techniques and expert systems for part of Nefza region.

Throughout this study, panchromatic band-8 was analyzed for automatic lineaments extraction under user suggested parameters values within LINE module of PCI Geomatica software. The lineaments extracted are characterized by variety in trend, length and density. Trends of these feature are (NE-SW), (N-S), (E-W) and (NW-SE).

In fact, the result of this study show a positive correlation between structural geology (faulting, lineament, warping) and the dominant extracted lineament orientations. Indeed, directional peaks recorded are consistent with results of previous work undertaken in the Nefza region.

To conclude, we can notify that automatically extraction of lineaments is a useful way to delineate lineaments for different purposes, such as defining geological structures over large regions.

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