



## Extraction and analysis of geological lineaments using satellite images, A Case Study: Zivah area, Mughan plain, Iran

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Article Info	Abstract
<b>Keywords:</b> Faults Remote sensing Magnetometry Landsat 8 Directional filters	Geological lineaments are an essential component of geological structure on the surface, and they are used in resource exploration for hydrocarbons, groundwater, and minerals. This study aims to extract lineaments from satellite images and magnetic data in the Zivah 1:100000 geological sheet. The lineaments were extracted using manual and automatic methods. Directional filters in different directions and hillshade technique were applied to manually extracted lineaments. Lineaments were automatically extracted using principal component analysis on the panchromatic band of Landsat 8, followed using the Segment Tracing Algorithm (STA). Magnetic data were used to extract basement faults and lineaments. The study observed that most fractures and lineaments in the region have an East-West trend and are extremely consistent in orientation with the basement faults in the Zivah area, suggesting that the systematic fault systems at the basement in the study area have been reactivated many times. The correlation between surface linear features and probable subsurface oil and gas traps (Anticlines) was also assessed, and the implication of using surface lineament and fracture analysis for delineating hydrocarbon reservoirs in the area was discussed. The highest density of faults and fractures was found in the central areas of Zivah, indicating that the areas might be a suitable bed for the accumulation of hydrocarbons. Therefore, the study recommends the use of surface lineament and fracture analysis as a cost-effective tool for hydrocarbon exploration in other parts of the basin.

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<https://doi.org/10.48306/jgrs.2025.494403.1011>

Received 13 November 2024; Received in revised 25 November 2024; Accepted December 2024

Available online December 2024

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## 1. Introduction

The application of remote sensing and GIS data has gained significant importance in the realm of structural geology. Experts utilize lineament extraction to enhance their comprehension of tectonic events. Geological lineaments refer to surface fractures that provide valuable insights into an area's lithology and structure. These topographic features are essential for various purposes, including exploration for natural resources like hydrocarbons, minerals, groundwater, and geothermal energy. Additionally, lineaments play a significant role in mapping susceptibility to hazards like earthquakes and landslides (Masoud et al, 2006; Masoud et al, 2011; Khosroshahizadeh et al, 2015; Sadiya et al, 2016). Linear features on the Earth's surface, known as lineaments, have a profound impact on the formation, migration, and properties of hydrocarbons like oil and gas. These hydrocarbon reservoirs are typically found in fractured rock formations, where fractures play a key role in hydrocarbon production. Through the analysis of remote-sensing data, we can determine the fault system's geometry and predict the vertical migration of oil from source rocks into tectonic traps in overlying formations. This analysis also allows us to estimate the volume of oil reservoirs. Faults have a positive impact on the petroleum geology of a region because during vertical migration, hydrocarbons from deep-seated horizons along the faults can enter upper trapping units and play a role in forming hydrocarbon accumulations (Zeinalov, 2000; Abdunaser, 2015).

In order to comprehensively examine the fracture pattern and its correlation with folding, as well as its impact on fluid movement, it is imperative to create a lineaments map (Afshari et al., 2016). The characteristics of lineaments, including their spatial distribution, density, intersection, and orientation, hold great significance. This is because lineaments serve as indicators of areas and trends that exhibit high permeability or low pressure, which can serve as potential hydrocarbon migration pathways. Additionally, these lineaments could reveal faults that govern the development of basins and the distribution of reservoirs. By integrating data from DEM, ETM<sup>+</sup> satellite imagery, magnetic readings, and seismic analysis, it is possible to enhance the ability to identify and chart geological structures in specific areas (Salehi et al, 2015). With recent developments in computer hardware and spatial analysis techniques, large-scale computer-aided analysis has been performed to describe geological and tectonic structures. Many methods have been proposed for automatic lineaments extraction from digital data such as satellite imagery and digital elevation model (DEM). Such methods are mostly based on edge detection techniques using spatial filters and morphology (Tripathi, 2000). Identification and interpretation of lineaments are usually done by using ground surveys and aerial photographs. Since in large areas, aerial photographs are not able to provide an integrated view of the area and due to the time-consuming and high cost of preparing lineaments and faults, these features are not accurately and completely identified. Lineament identification and interpretation usually involve ground surveys and

aerial photographs. Nevertheless, in expansive territories, aerial photographs may not provide a comprehensive perspective of the area. Additionally, preparing lineaments and faults can be costly and time-consuming, which may lead to incomplete and inaccurate identification of these features.

Over the last decade, satellite imagery, digital elevation models, and geological data have emerged as a dependable means of extracting lineaments. Among these, satellite images are especially valuable in pinpointing fault locations thanks to their exceptional resolution and spectral range. There are several techniques utilized for extracting lineaments from aerial and satellite images, ranging from manual digitization to image filtering. With the advent of advanced image processing techniques, automated extraction of lineaments from images has become feasible, resulting in the creation of multiple automated algorithms that provide enhanced efficiency and accuracy (Marghany, 2010). Numerous studies have employed remote sensing technologies to detect geological formations through the use of satellite images and digital elevation models. Baharvand et al (2015) successfully determined the heights of faults and fractures of the oil-rich anticline in Iran by applying linear filters in different directions on ETM<sup>+</sup> satellite images and constructing a hillshade from a digital elevation model. A comprehensive study on the Nader Anticline in the Kopeh-Dagh area of Iran was conducted by Afshari et al. using Landsat 8 satellite imagery. The research employed advanced automatic and semi-automatic techniques to identify faults in the area with a high degree of precision (Afshari et al, 2016). Through the application of edge brightening filters, such as Sobel-Gradient and Prewitt-G, on ETM<sup>+</sup> satellite images and digital elevation models, Beyk was able to uncover the geological structure of Mount Bangestan in the Zagros oil basin (Beyk, 2009).

Conventional geological and geophysical methods can verify lineament analysis of satellite imagery, but the results may not be comprehensive. However, many reports and papers discuss the analysis of subsurface lineaments interpreted from Gravity, Magnetic, and Basement structures. Al- Fastawi et al. used gravity data and seismic profiles in their analysis, which helped them interpret basement lineaments and correlate them with surface lineaments interpreted from Landsat TM and Radar images. They concluded that there is a strong relationship between surface and subsurface lineaments, particularly related to oil and gas fields (Al-Fastawi et al, 1990). Prabharan et al. (2013) utilized Landsat imagery to detect surface lineaments, and through the simultaneous analysis of seismic, magnetic, and gravity data, identified subsurface lineaments in the Cauvery Basin of India. Their findings shed light on the relationship between these lineaments and oil and gas traps in the area. Arafat et al. (2010) took a two-stage approach to studying the Sabatayn oil basin in Yemen. They first processed Landsat-8 images to identify surface lineaments, and then used seismic, magnetic, and gravity data to locate subsurface lineaments. Their work ultimately helped to explain the presence of oil and gas traps in the area. Chaabouni et al. (2012) conducted a structural mapping and tectonic interpretation study in the South Jenein area and its surroundings. Using spot Landsat images and Digital Elevation Models (DEMs), they analyzed lineament and fracture distribution to better understand the petroleum reservoir in the area.

This paper provides a detailed discussion of the significance of surface and subsurface lineament analysis in identifying hydrocarbon reservoirs in a particular study area. The approach involves utilizing satellite images, digital elevation models, remote sensing techniques, digitized geological maps, and magnetic data to create a map of surface and subsurface lineaments in the Zivah 1: 100000 sheets of the Mughan plain with acceptable accuracy. The final map is then adapted to the probable oil traps in the area. The fault structures at this scale were interpreted from Landsat 8 and Google Earth data.

## **2. Study area**

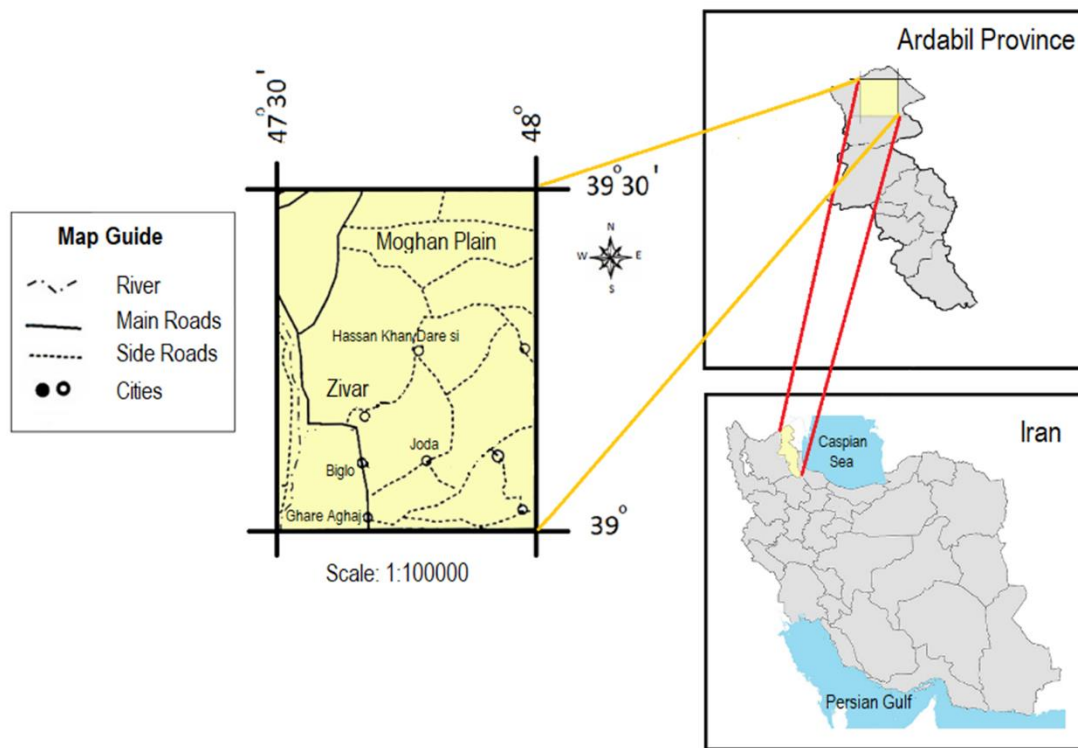
The study area can be found in northwestern Iran, situated in the northern part of Ardabil province and the Dasht-e Mughan. The Zivah area is located at a specific longitude and latitude (as depicted in Figure. 1). This particular area belongs to the Mughan Plain block, where the sediment thickness (containing abundant shale-clay strata) reaches over 8 km. It is an integral part of the Lesser Caucasus Anticlinorium, Talesh, and the mid-mountain range of the Kura depression - extensive structures that extend into Azerbaijan's territory. Figure 2 displays the geological map of the study area. Along with neighboring countries' lands, the southern and central areas of the Caspian Sea, this area is part of the Alpine fold system (a continuation of the Alborz fold belt).

The geological formations of the Mughan area and Khoroslu heights date back to the Miocene period up to the Quaternary period. Starting from the Aras coast, the formations can be briefly categorized as follows: (1) The Quaternary sedimentary formation of rivers and older sediments, composed of limestone, dolomite, conglomerate, and sedimentary materials that cover the northern part of the Mughan Plain up to the first barracks. (2) The Miocene sediments, consist of volcanic ash, sandstone, and, to some extent, sand, gravel, and conglomerate. Following these river formations, there are wind-transported materials in a significant portion of the southeast of the Mughan plain, with a height exceeding 50 meters. (3) The Pliocene-era formations, consisting of Neogene-era clay gypsum clays and salt gypsum massifs located southwest of Aslan Duz. Conglomerate sediments can be observed along this section towards the east. (4) The southern areas of Mughan encompass Garmi and Khoroslu heights, which belong to the Oligo-Miocene period. This formation, along with the volcanic material, extends almost straight from east to west and leads to the south of Khodafarin on the banks of the Aras River (Jafarzadeh et al, 2014; Aghanabati, 2005).

In terms of stratigraphy, the Middle Eocene Peshtasar Basalt, which runs in an east-west direction, adds to the evidence supporting Early Cenozoic extension. The area's Cenozoic succession began with the Qara Su Formation, consisting of sandstones and sandy marls interbedded with pyroclastic lenses, during the Late Paleocene-Early Eocene. The Middle Eocene is marked by the Ghara Aghaj, Shekarlu, and Salm Aghaji formations, which respectively contain shales, tuffaceous sandstones with numerous lava flows, interbedded shale, marlstone, and sandstone, and mudstone, marlstone, and sandstone. The

basin floor's Middle Cenozoic subsidence, combined with uplifting, folding, and thrusting along the southern basin margin during the Talysch-Lesser Caucasus orogenic belt's development, influenced the accommodation and sediment supply for the Ojaghgeshlag and Zivah formations during the Upper Eocene-Lower Oligocene and Oligo-Miocene (Amini 2003a).

The Turtonian Formation is composed of gypsiferous mudstones intermixed with dolomite, sandstone, and conglomerate. This formation reflects a decrease in both sediment supply and accommodation development during the Middle Miocene. At the end of the Miocene, there was significant uplift in the area and the Neogene sedimentary basins were closed, as evidenced by a regional unconformity at the top of the Sarmatian deposits. Based on studies of the Ojaghgeshlagh, Zivah, and Turtonian deposits, the Zivah Formation is associated with the Middle Oligocene-Middle Miocene period (Mogharebi 1972; Willm et al.1961). This formation is the temporal equivalent of the Shishnavar, and Melikassum formations in Azerbaijan. It's worth noting that the Oligo-Miocene Zivah Formation is a crucial siliciclastic unit in the area and serves as a significant hydrocarbon reservoir (Figure. 2) (Fotohi 1973).



**Figure 1.** Geographical location of the study area, Zivah, Mughan plain, Iran.

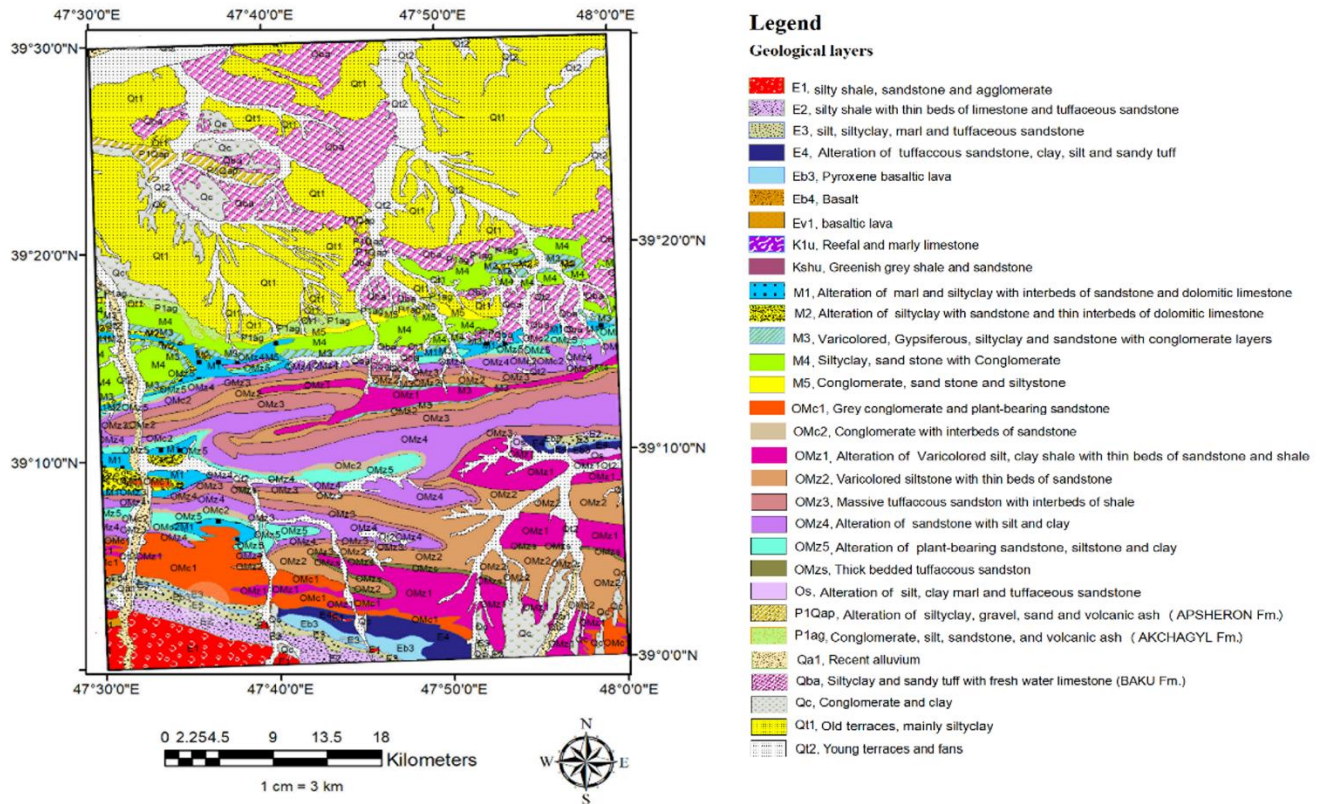
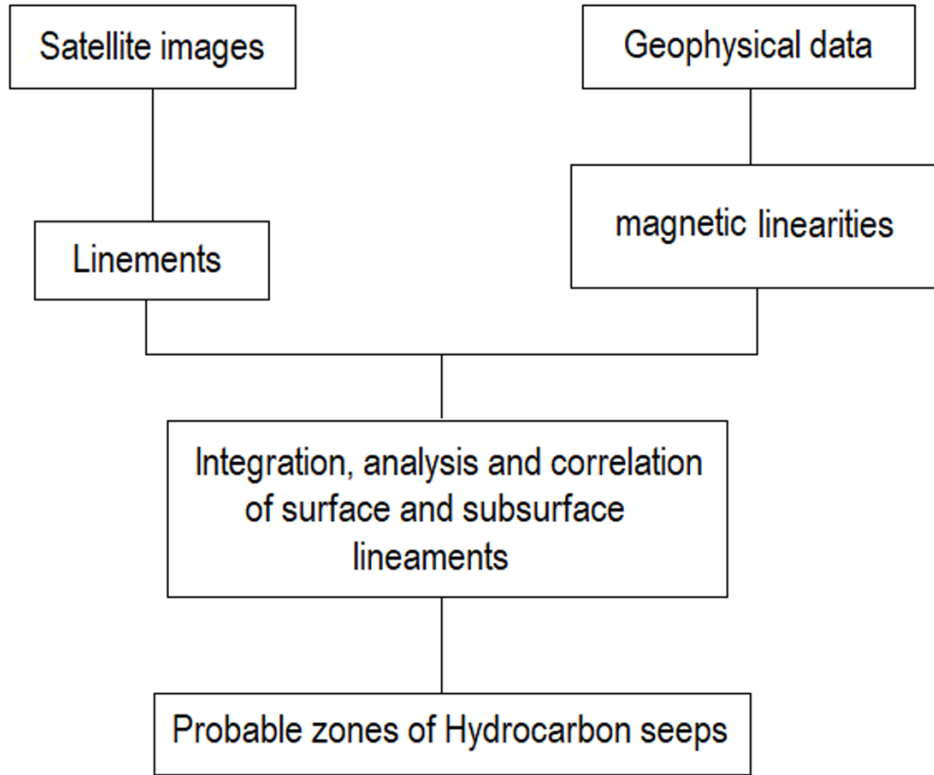


Figure 2. Geological map of the study area, Zivah, with scale of 1:100000.

### 3. Material and methods

This study utilizes a combination of satellite and geophysical data. Specifically, the spectral panchromatic band 8 of Landsat-8 OLI data was selected due to its exceptional spatial resolution of 15 meters, making it ideal for lineament analysis. The geophysical data used in this research was gathered by the National Iranian Oil Company through magnetic surveys conducted in the Mughan block, recording data from a total of 10,000 stations. Of these stations, 8,000 were part of a regular network spaced at intervals of 0.5-0.1 km, while the remaining stations were part of a regular network with intervals of 0.1\*0.1 km. The magnetic ground data for the 1:100000 geological sheet was extracted and separated from this data. This paper outlines an extraction algorithm for geological lineaments that comprises several main steps. Firstly, a digital GIS database is created using satellite, gravity, and magnetic data from various thematic maps, including surface lineaments, subsurface lineaments, and drainages. Secondly, the extracted lineaments from the different data sets are integrated using GIS technology. Orientation analysis is then performed on the lineaments to determine directional relationships. Finally, the significance of surface lineaments for oil and gas exploration in the study area is revealed. Figure 3 provides a brief diagram of the study method.



**Figure 3.** Methodology, the Flowchart shows steps for lineaments extraction and analysis.

## 4. Results and Discussion

### 4.1 Surface Lineaments Extraction

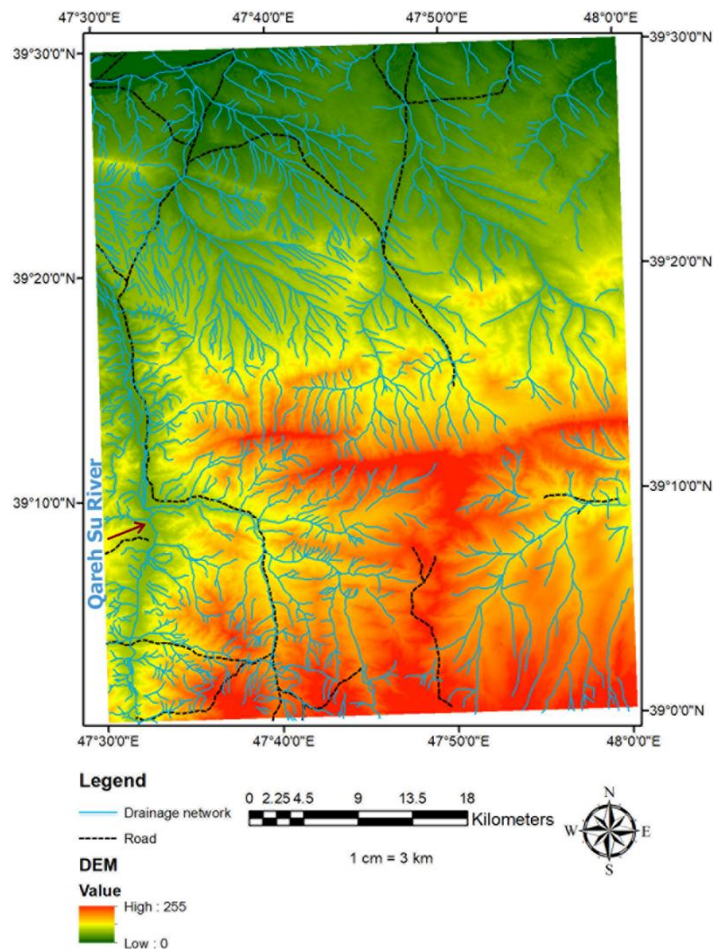
The extraction of geological lineaments from remotely sensed data can be categorized into three main approaches, including: (1) Manual (2) semi-automatic (3) automatic extraction. The extraction of the information from manual and semi-automatic approaches has been greatly influenced by the experience of the analyst, while automatic extraction, so far, depends on the algorithm's efficiency as well as on the information content in the image (Hassan et al, 2014). The best way to identify the lineaments of the area is by the correlation between the lineaments extracted by both the manual and automatic extracted techniques which is called the semi-automatic method (El-Sawy et al, 2016).

#### 4.1.1 Manual Lineaments Extraction, Using DEM, Hillshade, and directional filters

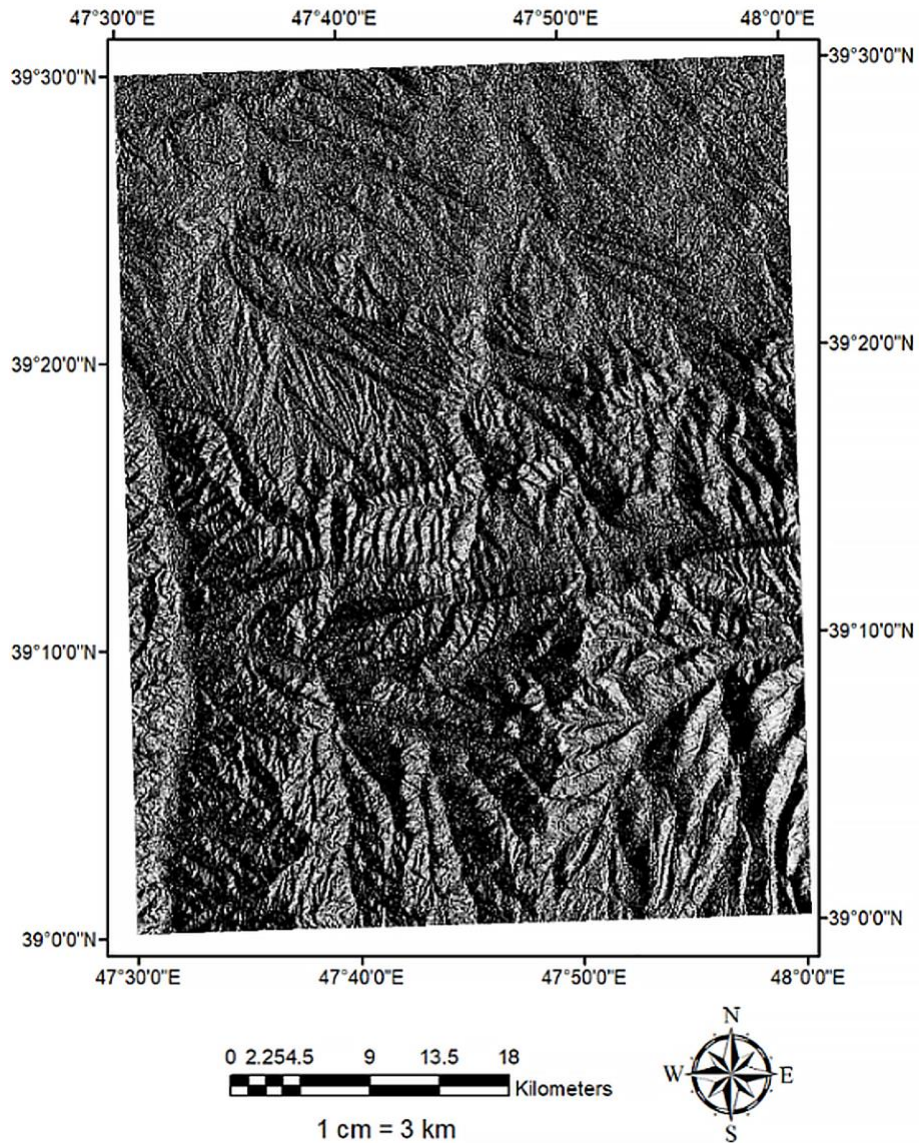
Analyzing digital models of land elevation and its 3D graphical representation can enhance the detection of lineaments. The shaded relief maps provide an advantage by illuminating topography from

any angle. However, aerial photographs and satellite images have a major limitation since they rely on natural sun illumination paths that highlight north-south lineaments, perpendicular to the sun illumination. Lineaments, which are identifiable by the boundaries between light and dark tones in shaded relief maps, indicate slope changes. By overlaying elevation contour maps and drainage pattern maps, lineament identification has been further improved, showing the exact locations of valleys, ridges, and slope breaks (Figure. 4).

Lineaments of tectonic origin are often linked to characteristic geomorphologic features such as linear valleys, ridgelines, and slope breaks, which can be identified in the DEM. DEMs have proven useful in detecting and mapping landforms and structural boundaries while providing a better understanding of spatial relationships (Saadi et al, 2009). The hillShade technique was applied to the digital model map of the 12-meter-high Zivah area under different azimuths (45, 90, 135, and 180 degrees) to serve this purpose (Figure. 5).



**Figure 4.** The pattern of water drainage and main roads in the study area of Zivah is drawn on the DEM map.



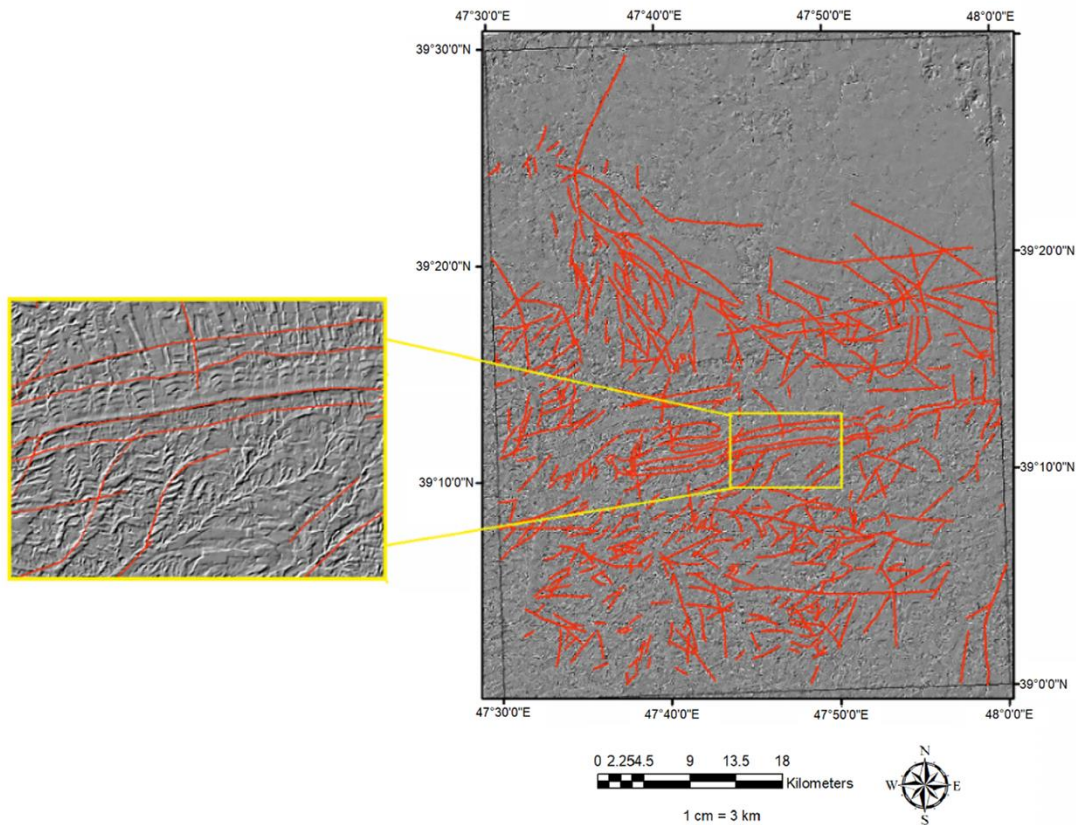
**Figure 5.** Applying the HillShade technique to the 45 degree azimuth.

Satellite images contain a parameter known as spatial frequency, which refers to the number of changes in brightness value per unit distance within a particular part of the image. Filtering operations can be used to either emphasize or de-emphasize the spatial frequency. This frequency is often associated with the presence of lineaments within the area, meaning that filtering operations can help sharpen the boundaries between adjacent units (Sarp, 2005).

The process involves using a matrix operator with a convolution mask that multiplies the kernel coefficient by the values of the base input pixel. The total value of the result is then attributed to the central pixel within the output image (Koçal, 2004 and Richards et al, 2006). For manual extraction of the lineaments from Landsat 8 satellite images, the 8-band was used due to its higher spatial resolution of 15 meters compared to other bands. Directional filtering was then applied to enhance, extract, and classify the oriented lineaments of the study area. Table 1 shows the directional filters used in this article to highlight the lineaments in four directions (0, 45, 90, and 135 degrees) as shown in Figure 6.

**Table 1.** Kernels in four principal directions.

45 directional filter, NE-SW			90 directional filter, N-S			135 directional filter, NW-SE			360 directional filter, N-S		
-1.41	-0.7	0	-1	-1	-1	0	-0.7	-1.41	-1	0	1
-0.7	0	-0.7	0	0	0	0.7	0	-0.7	-1	0	1
0	-0.7	1.41	1	1	1	1.41	0.7	0	-1	0	1



**Figure 6.** Manual lineaments extraction using the 45-degree directional filter.

### 4.1.2 Automatic Lineaments Extraction; Principle Components Analysis

A technique for processing on band d combination that compresses multi-band information into fewer bands by reducing the amount of data. Since the images of different bands in an area are correlated and provide the same information, the PCA method can be used to identify the desired effects in all bands in two or three components (Gupta 2003). Principal component analysis was performed on the Landsat-8 panchromatic band. In this study, the first component, due to having 80% of the information, was used to identify the lineaments of the region.

The LINE module of PCI Geomatica is the most widely used software for automatic lineament extraction. It provides different algorithms for automated extraction. Three common algorithms are applied, Haar transform, Hough transform, and Segment Tracing Algorithm (STA) (Koçal, 2004). STA is a method to automatically detect a line of pixels as a vector element by examining the local variance of the gray level in a digital image. 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 (Table. 2). As shown in figure 7, the frequency of automatically extracted lineaments is more than the manually extracted ones, but the accuracy of manually extracted data is higher.

**Table 2.** Suggested parameters values.

Parameter	Suggested values	Parameter	Suggested values	Parameter	Suggested values
RADI	5	LTHR	10	ATHR	20
GTHR	70	FTHR	3	DTHR	1

Due to the various factors present in the study area, such as the drainage system and man-made roads, the accuracy of the automatically extracted map can differ from the manually extracted lineament map. To assess the lineaments in the area, a useful tool is the drainage map. The movement of water over land surfaces is heavily influenced by the shape of the terrain, which is in turn shaped by a range of internal and external factors. As a result, fractures that are visible on satellite images can be identified by certain characteristic drainage patterns and sudden changes in flow direction.

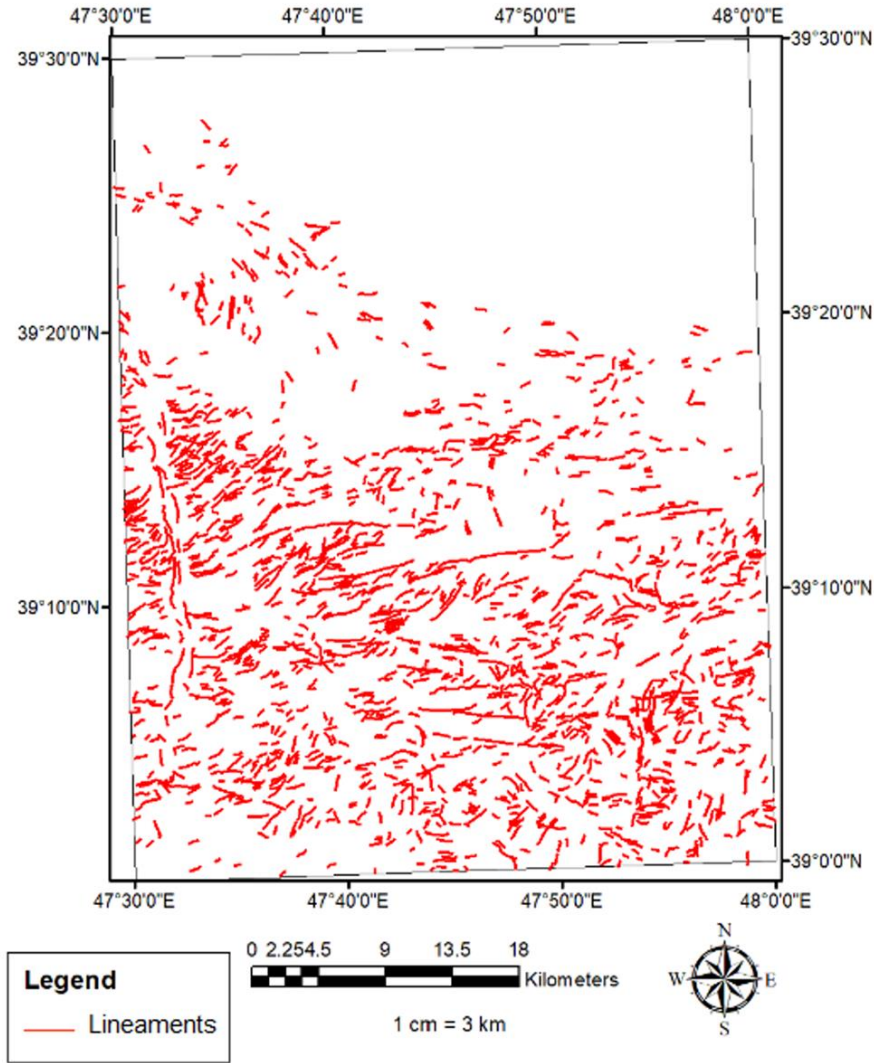


Figure 7. Automatic lineaments extraction.

#### 4.1.3 Semi-Automatic Lineaments Extraction

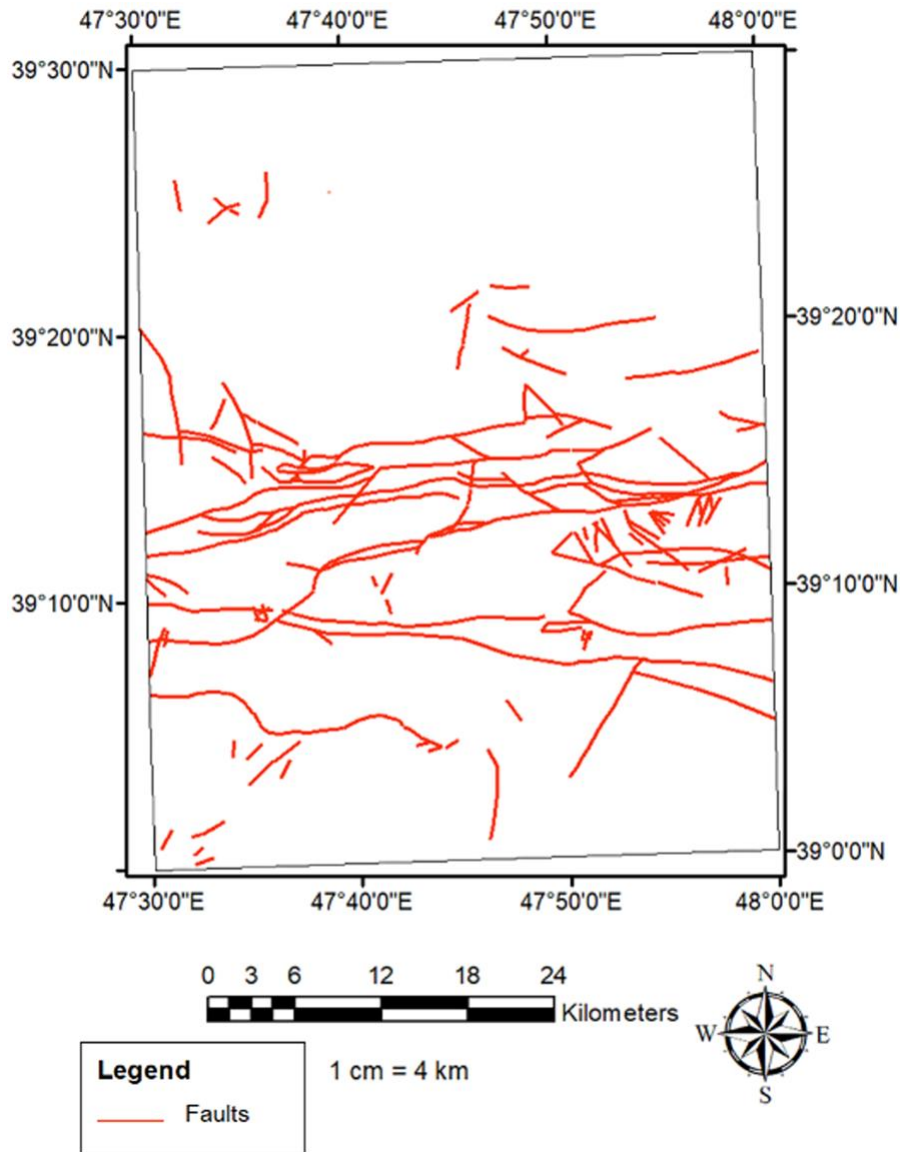
The most effective way to identify the features of an area is to compare the lineaments extracted manually and automatically. The Semi-Automatic lineaments extraction method combines both techniques, using automatic extraction as a starting point and correcting or completing it based on manual extraction. By overlaying the automatic map and the manual image, any missing or incorrect lineaments can be added or removed, resulting in a final supervised map. Of course, each lineament should be confirmed in the field for accuracy. Our goal is simply to evaluate the lines obtained through manual and automated methods. With the help of Google- Earth, the extracted lineaments can be further corrected for maximum precision (see Figure 8).



**Figure 8.** Example of verification of extracted lineaments (adapted from Google Earth).

#### **4.2 Basement Faults and Magnetic Lineaments**

In this study, the basement fault system map of the area was digitized from the geological map 1: 100,000 Zivah sheet produced by the Geological Survey and Mineral Exploration of Iran (Figure 9).

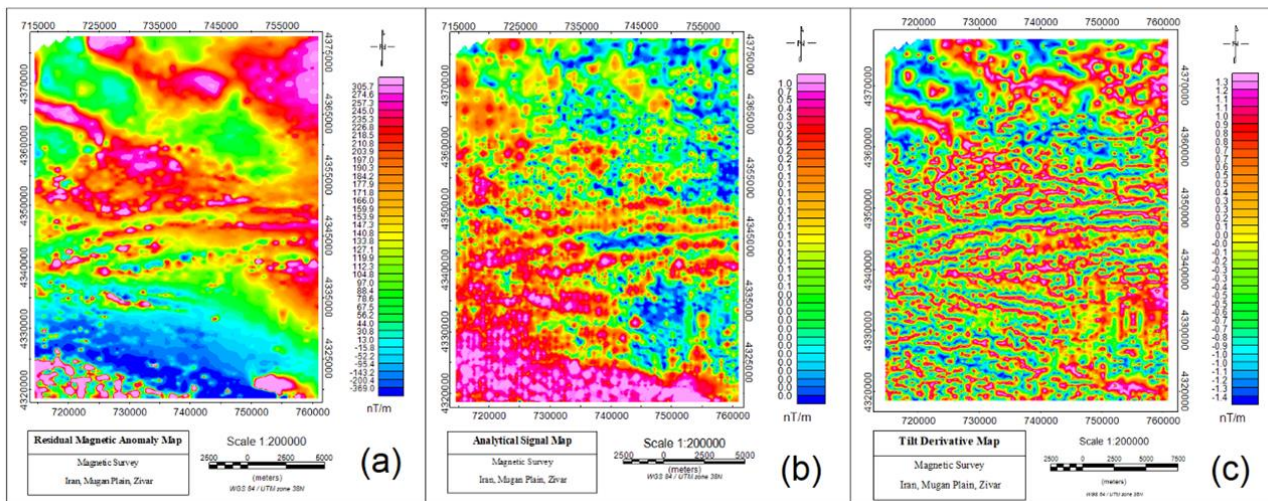


**Figure 9. Extracted lineaments and faults using the geological map.**

The Geosoft software was utilized to process the magnetic data, which was then plotted in 2D. To correct for diurnal variations in the ground magnetic data, the filtered and IGRF-corrected ground station data were subtracted. Once these corrections were made, enhancements were performed on the magnetic data to facilitate interpretation and analysis. Specifically, the analytic signal (AS) and tilt angle filter were utilized to detect tectonic faults and lineaments in this study.

To identify the detected lineaments as faults and shear zones based on magnetic contrast, the Tilt angle filter was applied, and the lineaments were subsequently identified (Figure 10). One of the major benefits of the TDR filter is that its zero-contour line is positioned directly on or near the faults or contacts, making it a valuable tool for estimating magnetic boundaries and lineaments.

Typically, certain characteristics found in magnetic maps can indicate regions of deformation. These include: (1) Linear and narrow lineaments and fractures with low magnetic intensity (blue), which signify areas of fragile deformation resulting from weathering along faulting surfaces and the oxidation of magnetic minerals. Both sides of this narrow, linear area can have similar magnetic properties. (2) Linear and narrow areas with high magnetic intensity (purple) may be cut off by an external agent or related to magnetic minerals deposited along faults. (3) Sudden disconnection in the depth of magnetic sources. (4) Discontinuities and displacements in turbulent magnetic anomalies, which are prominent indicators of a deformation zone. (5) Clear and rapid displacement in magnetic anomalies that suggest the presence of fragile zones or faults. (6) Magnetic ladders that represent contact surfaces with high crushing on different rock units. It's worth noting that uniform or gradual changes in the depth of magnetic basement rocks in a region may indicate a weak effect of faults in creating vertical displacement, or they may be the result of changes in the magnetic properties of deep materials. Additionally, it's important to keep in mind that the magnetic properties of deformed regions may change during different stages of metamorphism (Korhonen, 2004).



**Figure 10.** a- The total intensity map of the magnetic field, b- Analytical signal map, c- Tilt map of the study area; the zero contours (yellow color) represent lineaments and Faults. (Red areas indicate the high intensity of the magnetic field and blue areas indicate its low intensity).

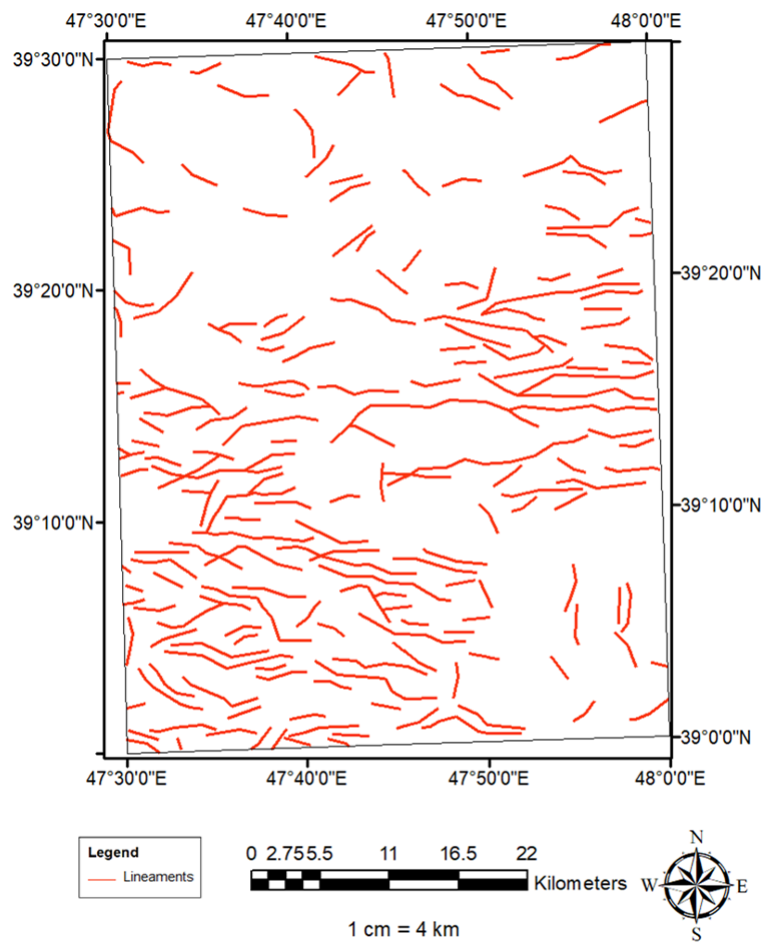
### 4.3 Geospatial and Orientation Analysis of Lineament

Density analysis has been applied to all extracted lineaments of the study area. The purpose of the lineament density analysis is to calculate the frequency of the lineaments per unit area. This is also known as lineament-frequency. This analysis will produce a map showing concentrations of the lineaments over the area (Greenbaum, 1985). Figure 12 shows the lineaments density map of the overall

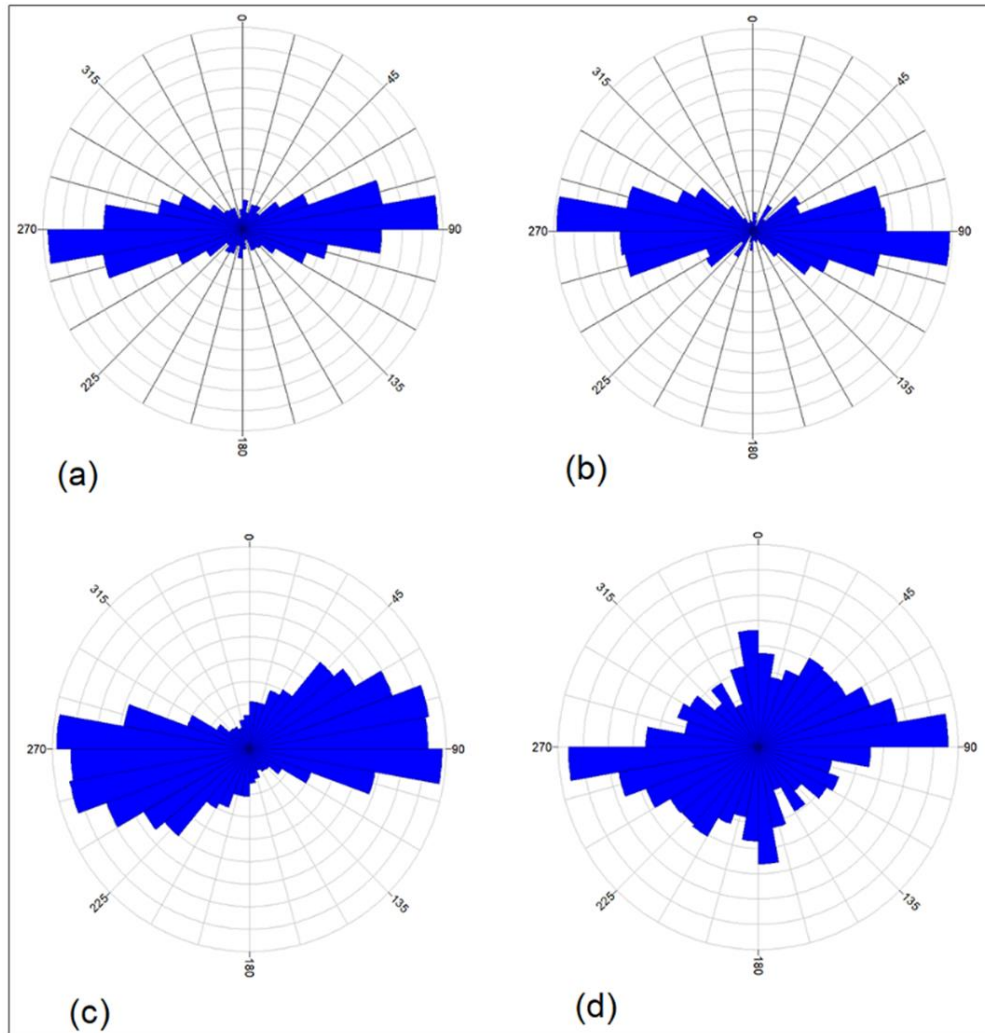
lineaments extracted from various methods. Geospatial analyses of lineaments give a good correspondence with the arrangement of the main tectonic forces of the studied area.

The extracted map shows that lineaments are highly concentrated at Khorosludagh and Digdash (Oligocene-Miocene sediments) and decreases gradually northwards. There is a complex folded zone in the north of Khorosludagh. It is split by numerous faults, mainly of sublatitudinal trend. The longest sublatitudinal areas of increased fracturing are controlled by long-living faults, while the lineaments are less concentrated in the south of Zivah (Eosen sediments) where no major faults are observed and the governing trend of igneous and basaltic mass is presented.

Lineaments orientations are usually analyzed by the rose diagram in all researches that deals with these structures. Figure 11 shows the directional frequency of the extracted lineaments over the specific area. Rose diagrams have been used to show the azimuth repetition rate of the lineaments according to their intended length. The amount of repetition in each direction depends on the length of the lineaments in that direction (Figure 12).



**Figure 11.** The lineament map deduced from TDR magnetic map.



### Legend

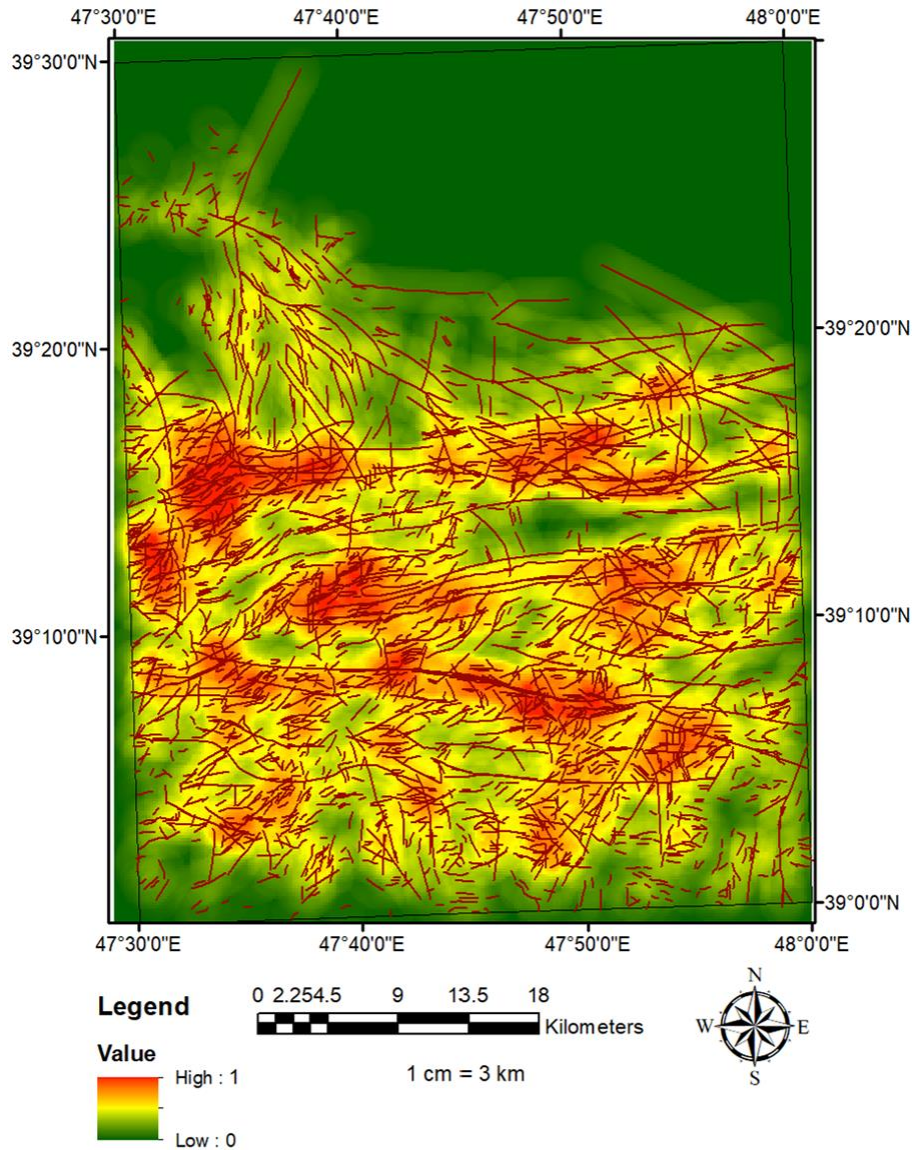
- (a) Lineaments orientation of basement
- (b) Lineaments orientation of magnetic data
- (c) Lineaments orientation of surface (automatic extraction)
- (d) Lineaments orientation of surface (manual extraction)

**Figure 12.** Rose diagrams a, b, c & d show orientations of lineaments derived from Basement faults system, magnetic and surface (satellite) data respectively.

Manually extracted lineaments on the surface appear in two sets of directions. The major set is oriented east-west, while the minor set is oriented north-south, although the latter is less common. These lineaments pass through many anticlines without changing direction, indicating that they are regional fractures that developed evenly in the pre-folding stages. They also provide appropriate weakness lineaments for the present drainage network in the area. The automatically extracted surface lineaments are primarily oriented east-west and are widely distributed. Overall, the manually and automatically extracted linear features in the study area share similar east-west orientations. The E-W structural lineaments mainly developed during the tensional phase in the back-arc basin and are related to the pre-folding phase. Magnetic lineaments are highly concentrated in the E-W direction, and the basement fault system in the study area is also oriented west-east. The consistent orientations among the basement faults, magnetic data lineaments, and surface linear features suggest that the systematic fault system in the basement has likely been reactivated many times and thus extends to the surface. As a result, these faults may have acted as propagators and conduits for hydrocarbons in the study area. Interestingly, some lineaments mapped from remote sensing data were not present in geologic maps, indicating that image lineament interpretation can provide new geologic perspectives even in areas that have been extensively mapped due to petroleum exploration.

#### **4.4 Significance of surface lineaments for oil and gas exploration**

The region boasts an integrated fracture system that spans the north and west, cutting through a significant sedimentary thickness that includes Baku, Eocene, and Miocene formations, as well as various anticlines and synclines. These structural lineaments follow the main river channels, such as the Gharah Su River, as shown in Figures 4 and 13.



**Figure 13. Lineaments density map of the manually extracted lineaments**

After overlaying surface and subsurface lineaments with oil and gas anticline locations (Fig. 14), it becomes apparent that the locations of anticlines are bound by major surface linear features on both sides. The geological faults, together with the surface and magnetic lineaments, define a network of potential migration pathways and structural conduits for hydrocarbons. The clustering of lineaments, particularly where different types intersect (e.g., surface and magnetic), indicates zones of increased permeability and fracturing, which are critical for both vertical and lateral migration of hydrocarbons. The surface lineaments run parallel to the subsurface basement faults, as observed in Ortadagh and Digdash anticlines. In the plunge areas of the anticlines, extensional systems are observable with a gradual change in direction, which is interpreted to be related to the folding phase. This is due to changes

occurring in strain lines associated with bedding strike changes and their impact on the fractures. Such results are apparent in areas close to the plunge area of the anticlines. Surface lineaments in the northwest of the region, on the Yuzquyi and Sarband anticlines, do not follow the faults and underground lineaments of the region and appear to be subordinate to the water drainage system of the region. Long thrusts along the anticlines, such as those on the northern slope of Ojaghgeshlagh, formed in the Zivah formation, can be categorized as long structural lineaments. They are typically parallel to the folds' axes and were formed during the folding phase, and they are abundant in the area. The north of the region has the least lineaments and faults and has more stable structural conditions, because of which potential underground structures for oil and gas reservoirs are not observed in this area. Zones with high lineament density and intersection frequency, particularly those coinciding with structural anomalies, are prime targets for further hydrocarbon exploration. Active oil seeps are located precisely over the surface lineaments, making them an excellent guide for structural contouring, facies mapping, and delineation of areas of fracture-enhanced permeability.

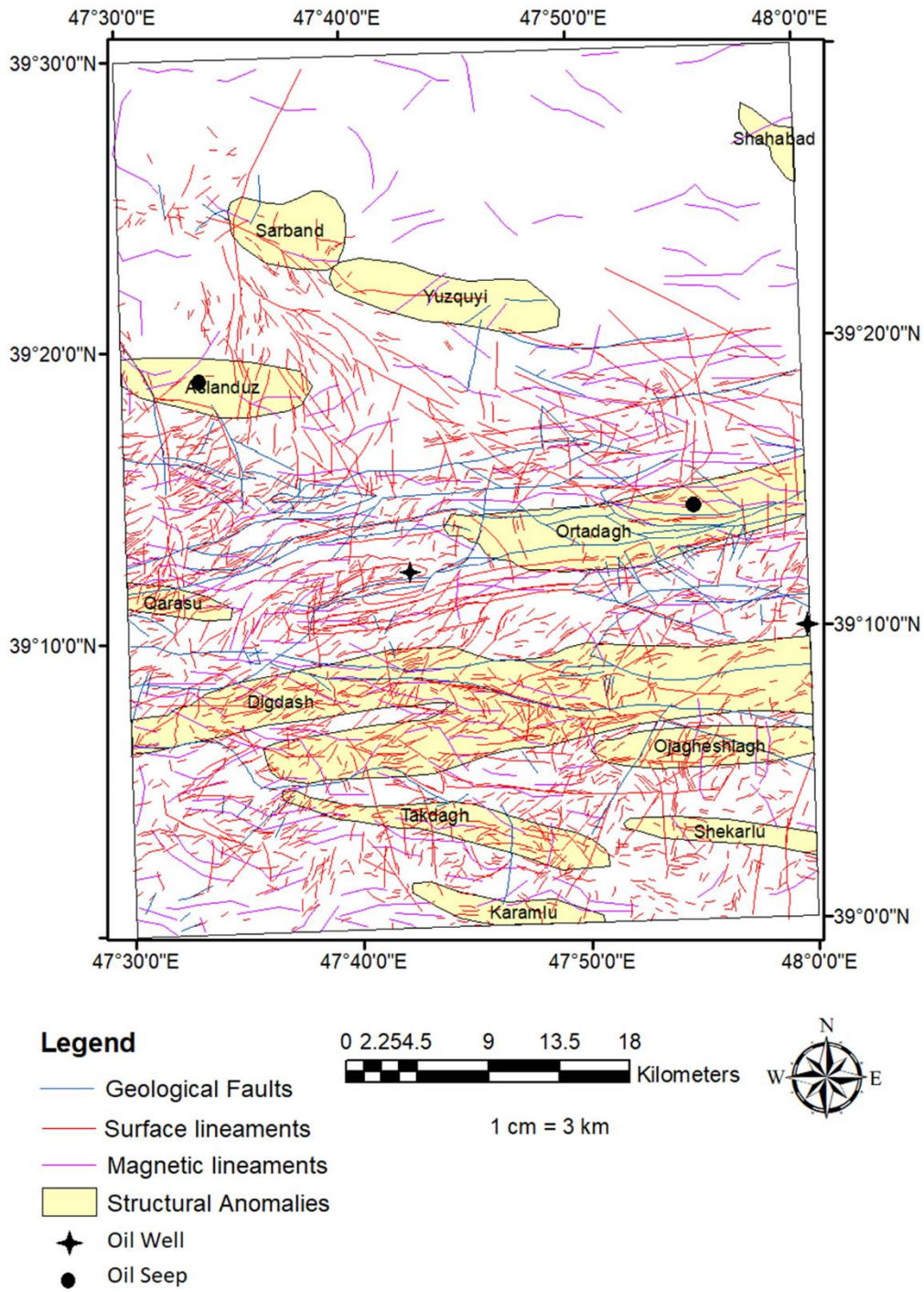


Figure 14. Integrated Lineaments of both surface and subsurface overlaid on anticlines the study area.

### 5. Conclusion

This study, based on remote sensing interpretation, has shown that in certain areas of the study region, oil and gas traps are well aligned with surface structural features such as folds, lineaments, and fracture

zones. These findings suggest that utilizing surface lineaments for oil and gas exploration could be significant in the Mughan basin, given the alignment between the oil and gas anticlines and the surface and subsurface linear features in the study area, particularly in the Ortadagh and Digdash anticlines. As a result, it is possible to conclude that if potential new oil and gas reservoirs exist in the other basins, they will likely be associated with surface lineaments. Therefore, employing surface lineaments as a cost-effective tool for delineating preliminary locations for more sophisticated and expensive geophysical or geochemical surveys in a basin is recommended.

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