DETECTION AND INTERPRETATION OF GEOLOGICAL LINEAR FEATURES ON THE SATELLITE IMAGES BY USING GRADIENT FILTERING AND PRINCIPAL COMPONENT ANALYSIS

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ABSTRACT:

Digital image processing has the ability to detect geological linear features on the image by using some algorithms. The most common algorithm which is used for this purpose is edge filtering. Gradient filtering is one type of edge filtering and is based on the calculation of the gradient along two perpendicular directions and obtain the largest absolute value of the two results. The directions of geological linear features are random in nature. One gradient filtering can be applied to only one specific direction for each time. So at least four or eight linear feature directions can be obtained for one specific area. The major dominant direction must be determined from these different directions. The filtered Landsat images are used for each directions. The principal component analysis is applied to all these filtered images for the detection of major direction. In the end, the result is verified with the tectonic lineaments of the studied area.

1. INTRODUCTION

Remote sensing which is a type of image processing has been used in geosience since 1970. Remote sensing has emerged as one of the main tool especially for the geological and geotechnical studies. One of the main aim of these studies are to detect the faults, stratigraphic boundaries and differentiate the lithologies. Some stratigraphic boundaries and faults have linear features that is the subject of this study. However, it is known that, these linear geological features can be seen easily by using ordinary satelite's black-white or colored composites, researchers tend to study on new methodologies for the detection of linear features more obviously. Faults which are one of the most common geological feature is important for earthquake studies. The fault which is not clear on the field, can be seen on the ordinary satellite images. Türkiye is the country, which is located on one of the most active tectonic region of the earth. Detection of linear features like faults, especially active faults is vital work after 1999 Marmara Earthquake.

The Landsat 7 ETM satellite image is used for this study. The studied region is located in the Middle Anatolia. Eskisehir, which is among the tenth biggest cities of Turkey is situated in the image. The area is bounded from north and south by rock mountains. It is known that the major tectonic directions are elongated NW to SE. The major active fault of the region passes just to the south part of the residental area. Many subsidary faults makes acute angle with the major fault or situated paralel to it. There are many non-geological linear features which are distributed randomly in the region. But the aim of the study is, to concentrated only for the geological features.

New methology is proposed for the detection of geological linear features in this study. The proposed methodology is to apply gradient filtering to the Landsat satellite band (ETM7) for different directions. Then principal component analysis is used to determine the most important direction for the studied area. Eigenvalues and eigenvectors of the analysis are evaluated for this purpose. In the end, the obtained image and the linear geological features on it are correlated and verified with the in-situ results. It is seen that, the linear features are seen more obvious at the end of proposed methodology and the tectonic lineaments of the region can be detected easily.

2. STUDY AREA

2.1 Location

Eskisehir is located in the northwest part of Middle Anatolian region of Turkey. With more than half million population, it is one of the biggest cities of Turkey and it is located between Ankara and Istanbul railroad (Figure 1). The studied area, covered by Landsat 7 satellite image which have path and row number 179 and 32 repectively. The acquired date of the image is October 1999. The studied area has extended approximately 40 km to 47 km on the N-S and E-W direction respectively.

Figure 1. Location map of the studied area

2.2 Tectonic situation of the region

The interested area belongs to Seismic Zone II, according to the General Seismic Zone Map of Turkey, which was prepared by Turkish Earthquake Research Institute (Annon, 1996).

North Anatolian Fault (NAF) is known as one of the most famous active faults of Turkey like San Andreas of United State. The distance between Eskisehir and the NAF is less than 100 km.

Eskisehir faced with deaths, injuries and serious damages during the last 1999 Marmara Earthquake, which had a magnitude of 7.4. In 1956, an earthquake of magnitude 6.4 according to Richter scale took place very close to Eskisehir (approximately 15 km west of it) and caused deaths, injuries and gave serious damages to severel structures. One of the subsidary faults of NAF which was named as Eskisehir Active Fault, also passes just south part of the urban area. It is the major interested linear geological feature of this study (Altan et al., 2004).

All these facts indicate that, Eskisehir is located in seismically active zone and linear faults must be detected and mapped for seismic hazard analysis as soon as possible.

3. METHODOLOGY

New methodology is proposed and used in this study for the recognition of geological linear features using satellite images. It is known that image processing of the satellite images has made important advances in geological researches during the last decates.

Geological features like faults can be easily seen in the band 7 of Enhanced Thematic Mapper (ETM). This band is the only band which used in this study. First enhancement technique like filtering is applied to the band. Then principle component analysis is used for finding the dominant direction.

Filter is defined as a tool designed to pass or block certain frequency components of an electric signals (Annon, 1996). An important field of application of filtering in image processing is edge detection (Altan et al., 2004). Edge detection depends on variations of digital pixel values of the image. Gradient Filtering is obtained to the digital image by finding the change in the digital value at succesive pixels in a particular direction (Girard et al., 2003). Gradient Filtering for eight different directions is applied to satellite image. Eight different bands are obtained from these procedure. Then the same procedure is applied for four major directions.

Principle component analysis is applied separately to the eight and then four new created bands to obtain the dominant direction in the region. The aim of the analysis is to find the dominant lineament direction of the region from the different gradient filtered satellite images. In the end, the results were verified with the original tectonic lineaments of the region.

4. DETECTION AND EVALUATION OF LINEAR GEOLOGICAL FEATURES

The spectral band 7 of Landsat 7 which covers 2.08-2.35 μm of electromagnetic spectrum, is used in this analysis. The pixel resolution of this band is 30×30 m. The Landsat ETM image used in this study is 1346 rows and 1588 columns. This is known as an important band for discrimination of geological rocks and detection of linear geological features like faults.

In the first step, Gradient Filtering technique is applied to this image. Gradient Filtering is also known as line detection. Eight different geological directions (N, NE, E, SE, S, SW, W, NW) are selected for this technique. The procedure of Gradient Filtering is to subtract the digital pixel value from the next pixel. The matrix coefficients which is used during filtering, change according to the displacement directions. Eight different bands are created from each Gradient Filtering operation. The new created bands are named as letter "b" with the number indicates the direction of maximum responce of the filtering. For example, b90 is the new created band is used by the east Gradient Filtering whose brightness value (BV) changes from W to E.

Principal component is one of the most often used analysis during the preliminary stage of the processing of satellite images (Jensen, 1986). Eight and then four different bands which are obtained from the Gradient Filtering are used as an input for the analysis. The aim is to find the principal axes of the principle component analysis. The data which transformed to these new derived axes do not correlate. The eigenvalues and eigenvectors are computed from the covariance matrix during the analysis. These values contain specific information for the interested purpose. The major purpose in this study is to evaluate the principal component analysis and detect the dominant linear features from the new transformed image which fit to tectonic lineament of the area.

At first, statistics values of the eight different bands of Gradient Filtering are obtained (Table 1). The covariance matrix of the bands are constituted for the calculation of eigenvalues and eigenvectors. At the end of the procedure, eigenvector loadings which are the linear combinations of eight different weighted input directional bands in the principal components are obtained. As it is seen in Table 1, the BV means of each bands are approximately equal (mean BV value is 11.0). It is seen from the evaluation of eigenvalues (Table 2), first three principle components (PC1, PC2 and PC3) accounts for 87 % of the total variance for the all filtered data. Evaluation of the magnitude, positive and negative sign of eigenvector loadings indicate which directions are more dominant on the image and how each principal component effect the directions (Table 3). It is understood that, bands b315, b0, b270 have high negative eigenvalues and they correspond to the dark pixels along NE-SW direction for PC1. The other directions on the PC1 which have positive sign indicate the lineaments along N-S direction as bright pixels. It is known, the dark pixels are seen more easily in the transformed image. The evaluation of PC2 indicate that, high negative eigenvalues of bands b45, b0 and b90 correspond to the dark pixels along NW-SE. It is known that, this direction is the most dominant direction of the studied region according to the tectonic situation of the region. Due to this, one of the highest eigenvector loading value -0.87 is obtained along this direction, b45, for PC2. The active fault of the area is seen obviously on the PC2 transformed image (Figure 2). The second result is the high eigenvector factor loading values. They are generally seen in the first three (PC1, PC2 and PC3) bands are adequate for the determination of geological lineations. PC1 is used for detect NE-SW; PC2 is used for NW-SE and PC3 is used for N-S type lineaments.

The same procedure is used only four major directions (N, S, E and W) for detection of linear features. The aim is to test the procedure with the previous one. It is seen that, except band b180, the other three bands have equal mean BV values (Table

Input Bands	b0	b45	b90	b135	b180	b225	b270	b315
Band Means	11,82	11,11	11,39	11,71	8,65	11,15	11,39	11,66

Table 1. Mean values of the eight different bands of Gradient Filtering

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Eigenvalues	1115,15	1014,86	682,92	195,60	185,22	23,99	10,69	4,96
%	34,49	31,39	21,12	6,05	5,73	0,74	0,33	0,15
Cum %	34,49	65,88	87,00	93,05	98,77	99,52	99,85	100,00

Table 2. Eigenvalues of principal components

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
b0	-0,65	-0,65	0,22	0,28	0,09	0,03	-0,09	0,00
b45	-0,09	-0,87	0,31	-0,13	0,33	-0,05	0,08	-0,04
b90	0,51	-0,60	0,49	-0,34	-0,10	0,07	-0,02	0,05
b135	0,69	-0,06	0,63	0,17	-0,28	-0,10	-0,02	-0,04
b180	0,43	0,44	0,63	0,42	0,14	0,20	0,08	0,00
b225	-0,11	0,72	0,58	-0,03	0,36	-0,10	-0,03	0,04
b270	-0,67	0,50	0,43	-0,32	-0,09	0,07	-0,02	-0,05
b315	-0,89	-0,10	0,31	0,08	-0,30	-0,04	0,07	0,04

Table 3. Values of eigenvector loading

4). These three principle components account for 88.77 % of the total variance (Table 5).

Evaluation of the eigenvalue factor loadings showed that, PC2 with a high value (0.86) and positive sign for band b0 is the best principal component for the studied area (Table 6). This direction almost fits to the geological features direction of the studied region. The new image of the region is obtained at the end of the principal component analysis with the four major directions (Figure 3).

The results of lineations of both images are merged with the tectonic lineations. The lineament of Eskisehir Fault Zone is seen on both images. But, the first created image by using eight different directions presented the lineation of the Eskisehir Fault Zone more obviously than the four directions data.

Input Bands	b0	b90	b180	b270
Band means	11,82	11,39	8,65	11,39

Table 4. Mean values of gradient filtering

	PC1	PC2	PC3	PC4
Eigenvalues	561,23	507,61	315,05	175,97
%	35,98	32,54	20,20	11,28
Cum %	35,98	68,52	88,72	100,00

Table 5. Eigenvalues of principal components

	PC1	PC2	PC3	PC4
b0	-0,46	0,86	0,01	0,22
b90	0,65	0,46	0,56	-0,23
b180	0,23	-0,40	0,57	0,68
b270	-0,80	-0,25	0,51	-0,20

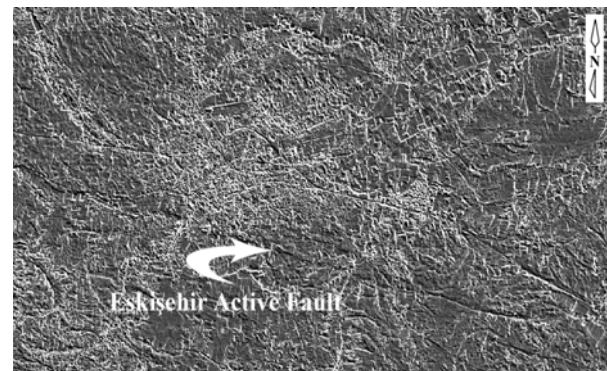Table 6. Values of eigenvector loading

Figure 2. The active fault of the region on the PC2 transformed image with 8 directions

Figure 3. The active fault of the region on the PC2 transformed image with 4 major directions

5. RESULTS AND RECOMMENDATIONS

The methodology proposed above is applied to the interested area and concluded that, principal component analysis accompanied by Gradient Filter technique improves the detection of linear geological features. Principal component analaysis by using eight different gradient filtered bands is found more effective than four major gradient filtered bands. At the results of the principal component analysis, PC2 is selected as the most effective for the studied area. High negative eigenvector loading values lineate the features more obviously than high positive values.

It is recommended that, this methodology is proposed to geologist for the detection linear geological features like faults from satellite images. The methodology must be tried and tested to the other areas for the verification.

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