Int. J. Environ. Res., 5(2):457-468, Spring 2011
ISSN: 1735-6865

Application of Remote Sensing in Monitoring of Faults

Yazdi, M.[1*], Sadati, N.[1], Matkan, A.A.[2] and Ashoorloo, D.[2]

[1] Department of Geology, Faculty of Earth Science, Shahid Beheshti University, Tehran, Iran

[2] Department of Remote Sensing and GIS, Faculty of Earth Science, Shahid Beheshti University, Tehran, Iran

Received 12 Sep. 2009; Revised 4 Aug. 2010; Accepted 14 Aug. 2010

ABSTRACT: The Siyah Bisheh area is located in central part of Alborz zone, 40km south of Amol, Iran. Rock units exposing in the area consists of sedimentary (carbonates, sandstone, siltstone), volcano- sedimentary (andesite to andesitic tuff, tuff), ignimbrite and basalt. when erosion and tectonics have rendered volcanic structures undetectable, remote sensing provides an invaluable tool for their identification, with finding relation between lithology and vegetation is showed that the integrated use of remote sensing techniques and field studies as a powerful tool to distinguish and map the relationships between rock units, structures and alteration zones associated with mineral deposits along the siyah Bishe area. The main image analysis techniques involved in this study were principal component analysis (PCA) and false color composite (FCC). In this study, an anomaly area is distinguished in the southeastern part of the Siyah Bishe area. Hydrothermally altered rocks contain economic mineral deposits whereas unaltered country rocks are non-mineralized. Approximately 5 km^2 of the area is underlain by altered rocks, but less than 1 km^2 of the altered area contains economic minerals.

Key words: Remote Sensing, ETM, Siyah Bishe, Central Alborz, Iran

INTRODUCTION

Landsat ETM remote sensing imaging allows precise coverage of vast regions with basic data for geological exploration while significantly reducing exploration costs. These data provide valuable information for geological mapping and mineral exploration through highlighting geological structures such as lineaments, faults and lithological contacts (Grandjean *et al.*, 2004). Such equipment has been widely used in environmental studies (Pijanowski *et al.*, 2009; Monavari and Momen Bellah Fard, 2010; Ehsani and Quiel, 2010).

The main image analysis techniques involved in this study were 1. Principal component analysis (PCA), 2. False color composite(FCC), 3. Band-ratio images and 4. Edge enhancement and filtering Techniques.

The prime emphases of this study are:

1- To determine the types of significant structure zones and find out its relation with alteration zones.
2- To determine the types of alteration zones and find out its relation with mineralization.
3- To find out key relation between the lithology of the study area and vegetation cover.

*Corresponding author E-mail: m-yazdi@sbu.ac.ir

MATERIALS & METHODS

The materials used in the research are as fallowing:

- Geological maps of the Amol Area at 1:50,000 and 1:100,000 scale.
- Topographic maps of the Shah zeyd area(No 6462-II) at 1:50,000 scale
- Radiometrically corrected Landsat ETM data in bands 1–5 and 7 of path/row 164/35, acquired on August 2002.

The procedure of research can be detailed within three steps:

a-Pre-field work(preparation of data)

-Collection of all existing data and information about the study area.

-Acquiring of information from ASTER, ETM and SRTM images.

-Digitizing the topographic map, geological map and ETM images.

-Unsupervised classification image for identification kind of units in the study area

-Normalized density vegetation index (NDVI), principle component analysis (PC) and false color composite with using edge enhancing filter.
-Digitizing the contour map and drainage pattern map for preparation of geochemical map.
b-Fieldwork
-Primary survey of the study area and general geology.
-Checking information on the basis of unsupervised classification, PC, FCC and NDVI of ETM images.
-Sampling of altered zones
c-Post field work
-Preparing of samples and analysis of them with XRD method.
- Correction of Geological maps at 1:50,000 scale on basis of aerial photos and preparation geochemical and alteration maps at the same scale.
- Processing and analysis of earth data and satellite images.
-Performing supervised classification methods with used of training samples and comparing with unsupervised classification.
-Field study of anomaly area.
- Analysis and incorporation all of data for mineral exploration

RESULTS & DISCUSSION

The study area covers about 90 km^2 in the Siyah Bishe region that lies in central part of Alborz zone, 40km south of Amol. The area has a humid climate, mountainous topography, developed soil and dense vegetation cover. The study area lies between latitudes 36° 4' 59'' - 36° 9' 18'' N and longitudes 52°16' 54''- 52° 24' 43'' E. On basis of geologic map of the Amol Area at 1:100,000 scale, Rock units exposing in the area consists of sedimentary [carbonates(J1, Jd, KT , K21, K2M1), Gypsum(K1g), sandstone and siltstone(J)], volcano- sedimentary [andesite to andesitic tuff(K2V), tuff], ignimbrite and basalt(K1V)(*Allenbach, 1963)*(Fig.1).Hydrothermal alteration involving chlorite, sericite, epidote, carbonate, silica and clay minerals are common. However phyllic, argillic and propylitic alteration are more common in the area.

Selected points from a previously rectified planimetric map of Siyah Bishe area were matched with the equivalent points on the unrectified satellite image. The computer ''resampled'' the whole image and ''drew''a new rectified satellite image to match the planimetric map. Additional points were selected to reduce rectification error to a minimum. As a check on this approach, previously digitized and rectified geologic and topographic maps were overlain on the image with excellent equivalency (Sadati, 2009).

Different RGB color combinations were examined and the 7-5-3, 5-3-1 and 4-7-2 Landsat TM images proved to be the best for visual interpretation. Color composite images (bands 5-3-1) most useful for distinguishing rock types in the study area (Fig. 2).

Band-ratio images are produced by dividing the digital number(DN) values of one band by the corresponding DN values of another band and displaying the new DN values as grayscale image(Novak &Soulakellis, 2000). The selection of the bands that will be used in the development of bandratio images depends on the spectral characteristics of the surface material to be analyzed and the abundance of this material relative to the surrounding (Thurmond *et al.*, 2006). Surface weathering on most of hydrothermal

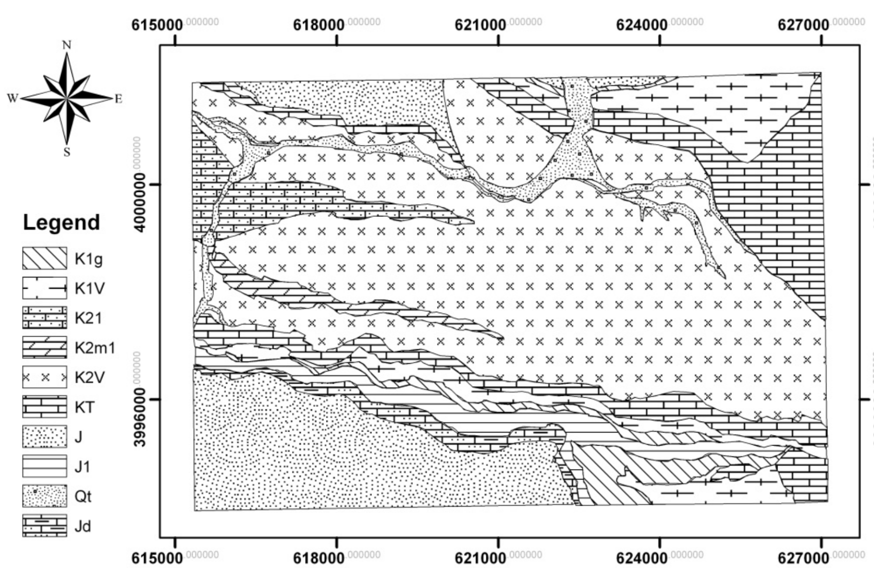

Fig. 1. Geological map of the Siyah Bishe area at 1:50,000 scale

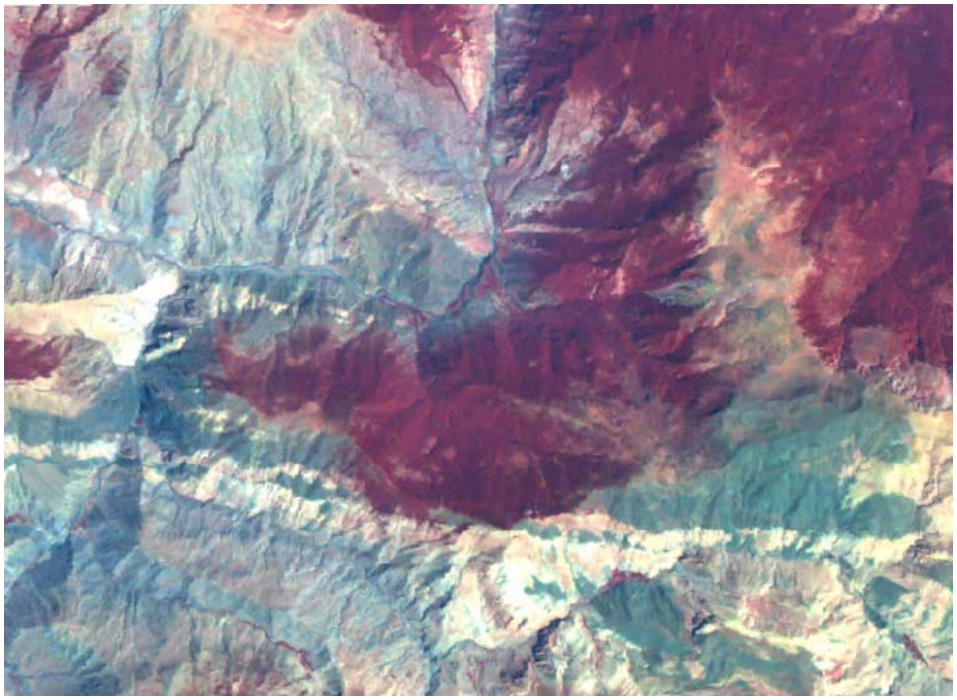

Fig. 2. Landsat TM color combination image (bands 5-3-1 in red, green, blue) for study area

sulphide deposits causes the formation of iron oxide-bearing minerals. Therefore, this spectral characteristic has been extensively applied in exploration of hydrothermal sulphide deposits (Ranjbar *et al.*, 2004). band ratio 3/1 effectively maps iron alteration as the iron minerals such as limonite, goethite and hematite have reflectance maxima within Landsat TM band 3(visible red light) and reflectance minima within Landsat TM band 1 (visible blue light) Hence Landsat TM band ratios 3/1(Fig. 3) increase the differences between the digital numbers (DNs) of iron alteration zones and those of unaltered rocks respectively (sabins, 1999). This leads to a better discrimination between hydrothermally altered and unaltered rocks in the present area.

The band 5/7 ratio (Fig. 4) is sensitive to the hydroxyl mineral content of the rocks, such that areas of high 5/7 values have relatively high hydroxyl mineral contents (Timothy, 2001). Because of resemblance

Fig. 3. Landsat TM ratio image (bands 3/1) for study area

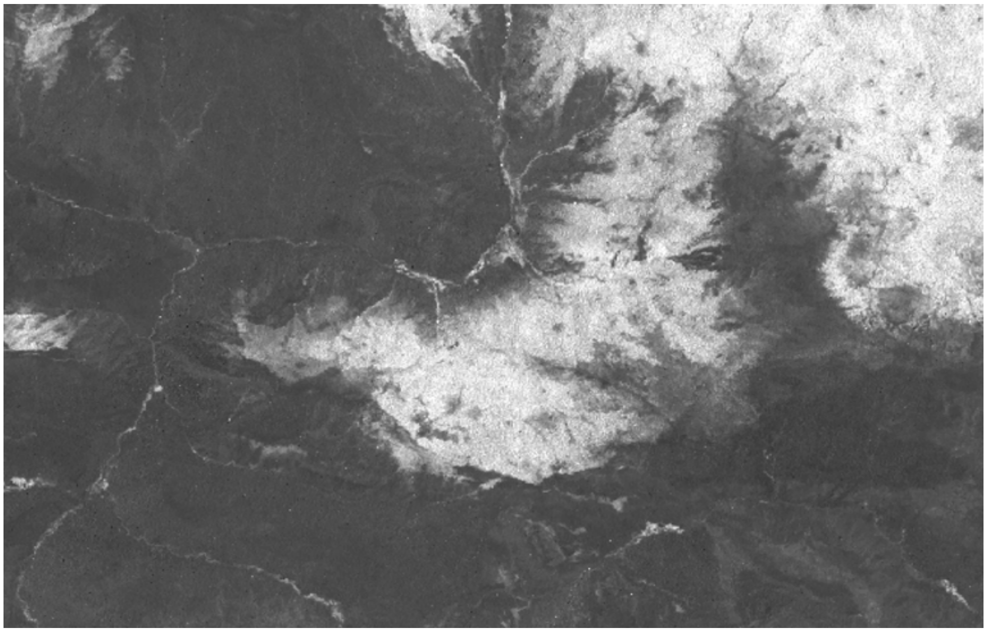

Fig. 4. Landsat TM ratio image (bands 5/7) for study area

between reflection of hydroxyl mineral and vegetation cover, we compare this band ratio with NDVI image to distinguish them from each other.

Color composite ratio images are produced by combining three ratio images in blue, green, and red. Fig.5 shows ratios 5/7, 4/5, 3/1 in red, green, and blue, respectively. In this image the argillic alteration zone is seen as pink color, volcanic rock is seen as green color and iron oxides is seen as blue color (Fig.5). Ratios 5/7, 3/1, 3/5 in red, green, and blue, respectively combines the distribution patterns of both iron minerals and hydrothermal clays. Therefore an average of hydroxyl and iron oxide images is also obtained and a false color composite image may be created (Fig.6).

Finally, ratios 3/1, 5/7, 4/3 in red, green, and blue, respectively (iron oxide image in red, hydroxyl in green and vegetation cover in blue) is used as an important index in explorations for distinguishing alteration zones (Fig. 7).

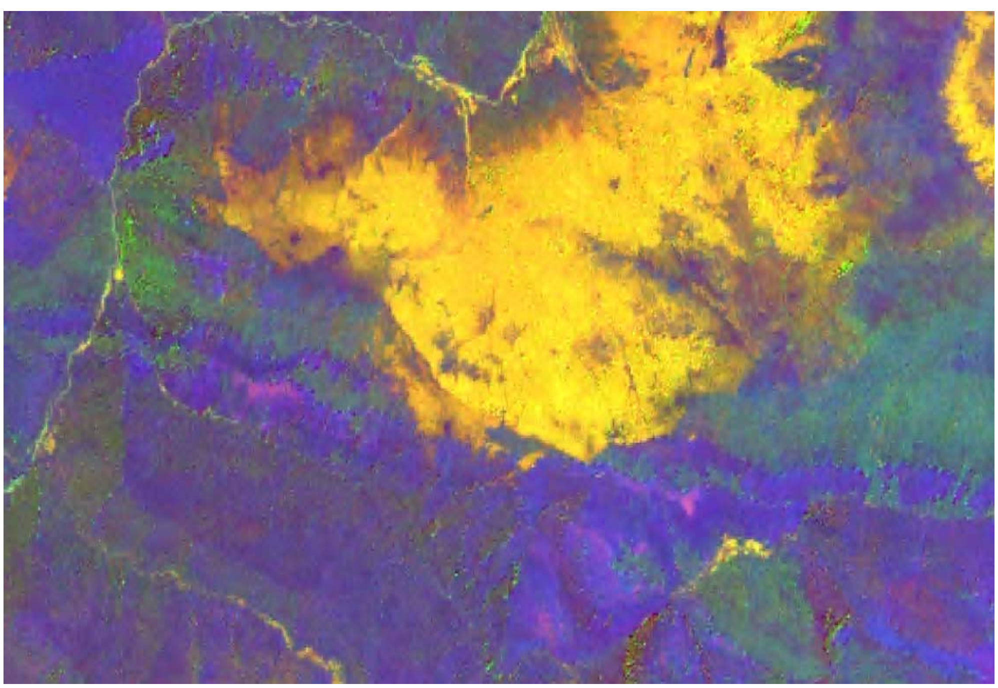

Fig. 5. Landsat TM ratio image (bands 5/7, 4/5, 3/1 in red, green, blue) for study area, showing the argillic alteration zone with pink color

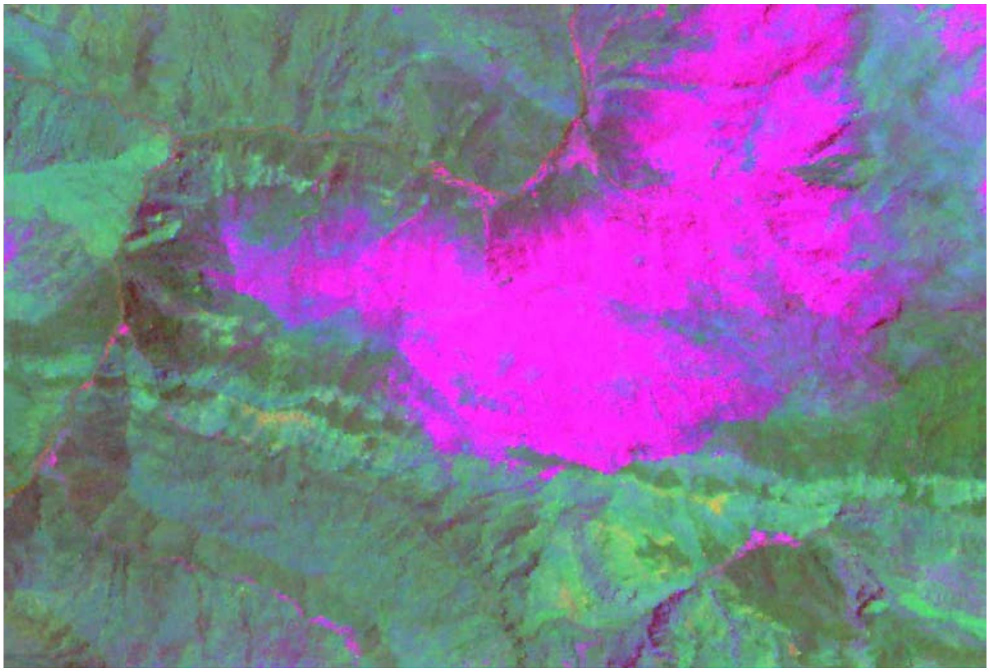

Fig. 6. Landsat TM ratio image (bands 5/7, 3/1, 3/5 in red, green, blue) for study area, showing the argillic alteration zone with yellow to red color

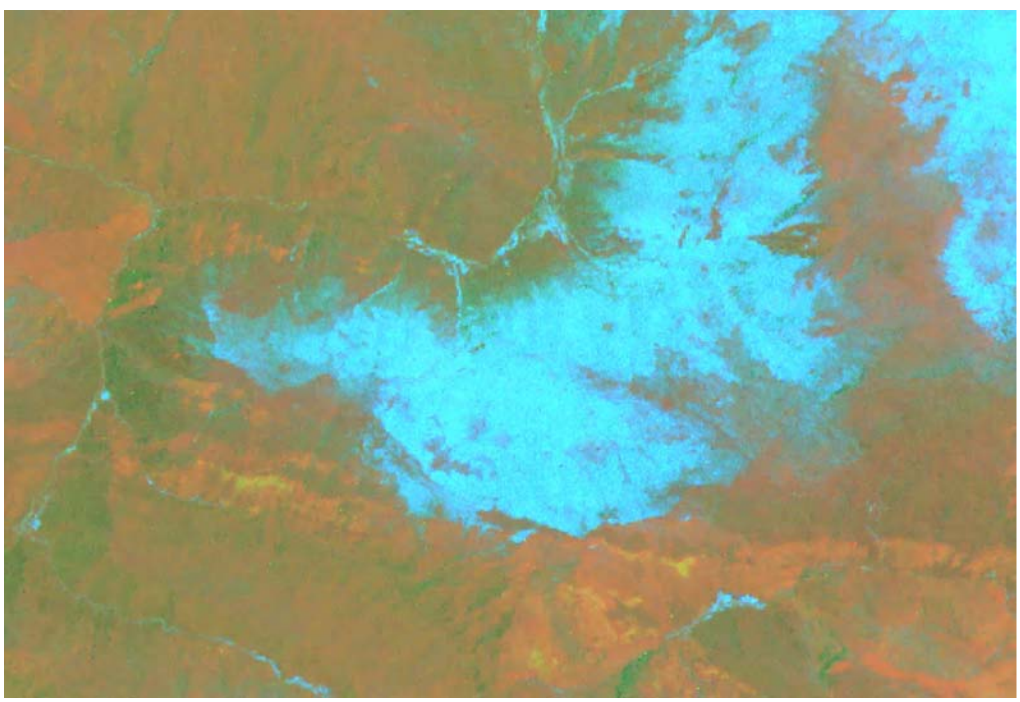

Fig.7. Landsat TM ratio image (bands 3/1,5/7,4/3 in red, green, blue) for study area, showing the argillic alteration zone with green color

The ratio images were interpreted to identify areas with high concentrations of iron oxide minerals and clays. These areas, called anomalies, were plotted on a preliminary map (Fig. 11). The TM anomalies were evaluated to eliminate false anomalies. Three major types of false anomalies are:

1. Sedimentary rocks, such as shale, that is rich in clay.
2. Rocks with an original red color, such as iron-rich volcanic rocks and sedimentary red beds.
3. Detritus eroded from outcrops of altered rocks; these recent deposits in alluvial fans and channels may indicate the proximity of altered rocks.

The altered areas are checked in the field. Rock samples have been collected from the area and analyzed based on XRD and thin section studies. The collected samples have shown that the areas shown as altered parts in the volcanic areas are sericitized and argillized. There are small areas which are classified as altered in the sedimentary parts of the area. This is due to the fact that the rock fragments accumulated in these parts are derived from the intrusive bodies in the volcanic area.

Principal component analysis is widely used for mapping of alteration in metallogenic provinces (Ranjbar *et al.*, 2004). In the resultant image all intensely hydrothermally altered areas are shown as bright pixels (Marked by ellipses in Fig. 8). The moderately altered areas are seen in a yellowish brown color.

This technique is used on 4 Bands (Bands 1, 3, 4 and5 for enhancing iron oxides and bands 1, 4, 5 and 7 for enhancing hydroxyls). The only disadvantage with using this method on 4 bands is that the sedimentary rocks and the areas with mild hydrothermal signatures are also enhanced in the resultant image (Ranjbar *et al.*, 2004).

color composite ratio images]5/7 ,PC2(5,7), PC4(1,4,5,7)] most useful for distinguishing alteration zones in the study area(Fig.8).Lineaments are natural simple or composite-pattern linear or curvilinear features discernible on the Earth's surface. In the geologic sense, these features may depict crustal structure or may represent a zone of structural weakness. These originate mainly from strains that arise from stress concentrations around flaws, heterogeneities, and physical discontinuities, largely reflected in the form of faults, fractures, joint sets, or dykes. They form in response to lithostatic, tectonic, and thermal stresses and high fluid pressures. They occur at a variety of scales, from microscopic to continental. Fractures are important in engineering, geotechnical, and hydro geological practice because they provide pathways for fluid flow (Alaa, 2006).

Attention was paid to exclude linear features that do not correspond to geological structures and those which were introduced during digital image processing of the remote sensing data. These include man-made linear features such as roads and crop-field boundaries as well as missing lines in the remote sensing data (Solomon & Ghebreab, 2006).

Landsat Thematic Mapper images have been used for detecting and analyzing tectonic and volcanic structures in this area. Lineament mapping is based on visual interpretation of various Red–Green–Blue (RGB) color combination images enhanced by Principal Component Analysis (PCA), and grayscale images such as Landsat TM band 5.

Conventional lineament extraction techniques were commonly based on visual interpretation and hand-tracing of linear features depicted on aerial photographs

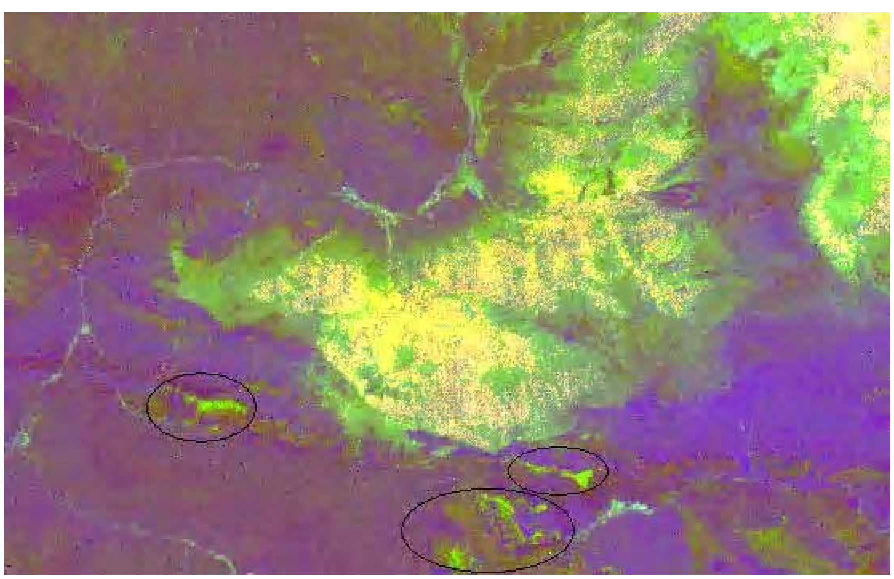

Fig. 8. Landsat TM color combination image [(5/7 ,PC2(5,7),PC4(1,4,5,7)] (in red, green, blue) for study area

or paper based satellite image mosaics (Alaa, 2006). Regional scale joints and fractures are well recognizable in the satellite imagery in terms of moisture anomalies and vegetation alignments.In addition, geomorphologic features such as aligned ridges and valleys, straight drainage channel segments and linear scarp faces are considered to mark major lineaments. Most commonly applied approaches for lineament extraction are based on edge enhancement and filtering techniques (Alaa, 2006). Although major lineaments can be detected from the Landsat TM RGB color combination and grayscale images, additional small lineaments become clearer in the filtered images (Fig. 9).

Nevertheless, because surface expression of some of the lineaments is smaller than the spatial resolution of the Landsat TM data, these techniques produce short dense lineaments that are difficult to relate to tectonically significant structures. In totally, Faults and lineaments of the Siyah Bishe area were located in two groups according to their directions: one NE–SW and the other, NW–SE.

The lineaments were identified by visual interpretation of satellite images, using false color composites from the Landstat TM Data(Table1). From the comparison of all ETM+ bands, it was observed that the ETM-4 and the ETM-5 bands provided the best visualization of the lineaments. The 5-4-1 Landsat TM image proved to be the best for visual interpretation. Identification of lineaments from the 5-4-1 and PC1–PC2– PC3 Landsat TM images is mainly based on color differences at the boundaries of contrasting lithological units, breaks in crystalline rock masses and visible faults.

Table1. Best color combinations in RGB for structural analysis

(Solomon & Ghebreab, .2006)	visual interpretation	541
(Chernicoff et al., 2002)	regional structural analysis	741,742
(Saintot et al., 2000)	structural analysis and the main lineament trends	457

The PCA technique provides a systematic means of compressing the multi-spectral image data with the aim of reducing the redundancy in the different bands. This technique was also performed to enhance lineament detection. PCA is used in order to reduce spectral redundancy in the Landsat TM data and to represent entire spectral information in a single RGB color combination image (PC1–PC2–PC3) (Solomon & Ghebreab, 2006).

Some 20 combinations of original image bands and/or principle components (PC) were tested for image enhancement qualities. Of these, six offered satisfactory enhancements in FCCs in red, green, and

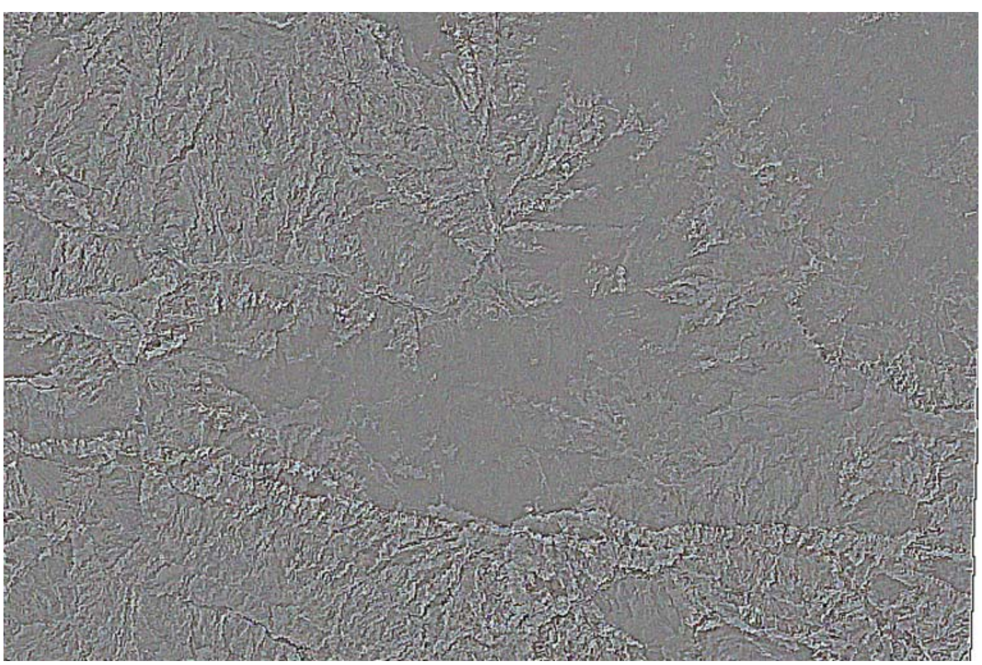

Fig. 9. Fault extraction by enhancement and filtering techniques

blue (RGB). Of these six, two were the most acceptable busing topography, drainage, and lineament definition as criteria for selection. One of the two was composed of original TM-band 3, PC-1, and PC-2; and the other one was composed of original TM-band 7, PC-1, and PC-2. The latter combination offers slight advantages because it includes the first and second axes of PC images along with band 7 which is the most appropriate band for geologic investigations (Fig.10).

The two PC-images and TM-band 7 were combined to produce a final FCC image by assigning each image to a separate primary color) RGB (. This final digitally enhanced image was interpreted for geologic and geomorphic features. (Novak & Soulakellis, 2000). These fracture zones were validated using field investigations and the available structural studies in the area.
Field and remote sensing studies indicate that most of the lineaments are extensional fractures that correspond to either dikes emplacement or normal faults.

Supergene alteration has produced extensive limonite and leaching of sulfide, giving a characteristic reddish or yellowish color to the altered rocks that in Landsat TM band ratios 3/1 they look brighter. Overlapping of the alteration and fracture map has shown that the hydrothermally altered rocks are highly fractured (Fig.11).

In this study, an anomaly area is distinguished in the southeastern part of the study area (Fig. 12); hydrothermally altered rocks contain economic mineral deposits whereas unaltered country rocks are non-mineralized. Approximately 5 km^2 of the area is underlain by altered rocks, but less than 1 km^2 of the altered area contains economic minerals.
Field observations have shown that, many altered areas do not show geochemical anomalies but have a strong signature in the satellite data. At the same time there are altered areas which have good presence in the geochemical data but are not seen in the satellite data. For mapping such areas, integration of satellite and geochemical data can be helpful.

The application of the vegetation index NDVI was considered as a quantitative measure of vegetation content and vigor (Fig. 13). Vegetation is an indicator of certain lithologic sub-classes, and is interrelated with water penetration and susceptibility to erosion. In the present work, NDVI image has been applied to distinguish relation between volcanic rocks, soils and vegetation cover. The land around volcanoes is intermittently attacked by pyroclastic flows, volcanic ash deposition, lahar deposition and so on. These volcanic ejecta are named tephra. After tephra deposition, soil formation starts. Soils derived from volcanic products cover about 0.84% of the world land surface. These areas because of a low bulk density, high organic matter content, high porosity and high

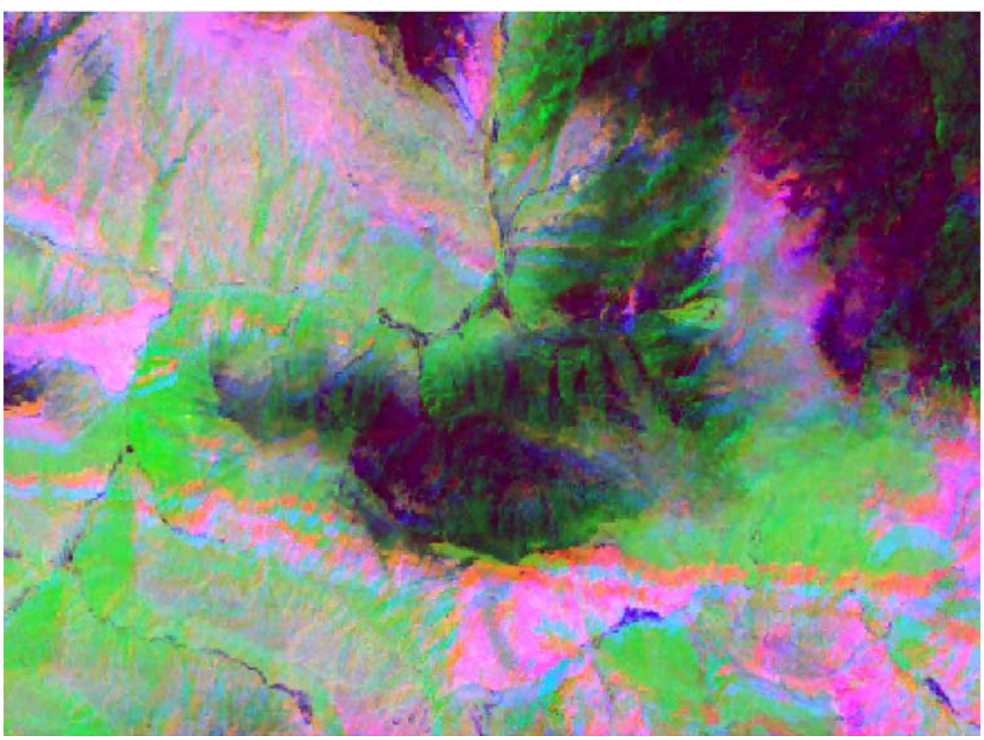

Fig.10. Landsat TM color combination image (PC1, PC2, band7 in red, green, blue) for study area

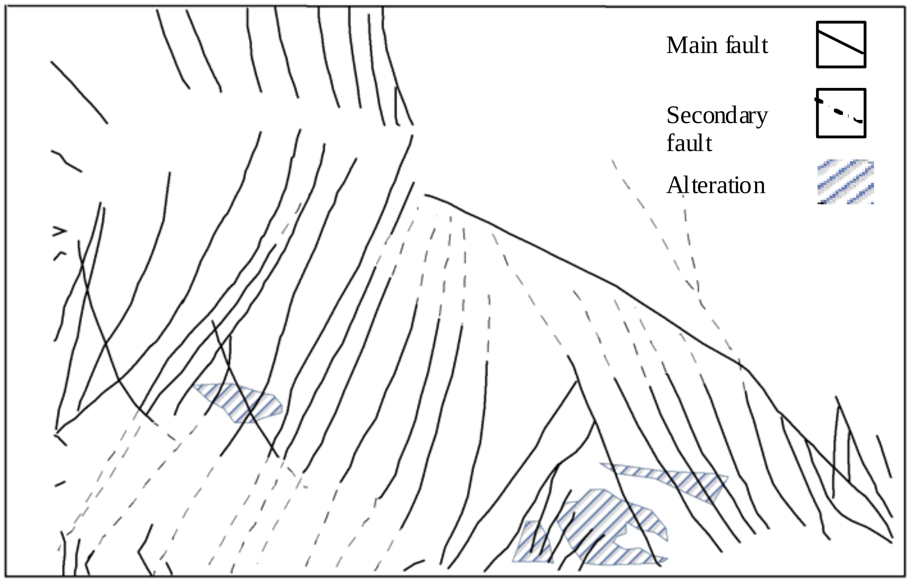

Fig.11. overlapping of fault and alteration maps copper in the Siyah Bishe area at1:20000 scale

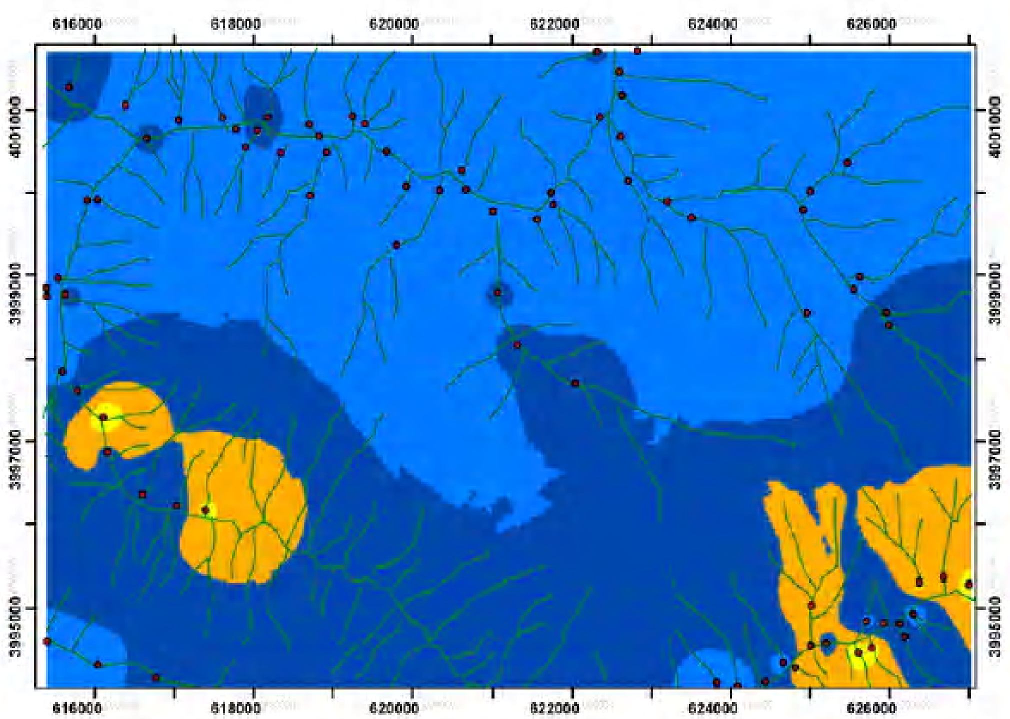

Fig.12. Geochemical map of copper in the Siyah Bishe area at 1:20000 scales

water retention capacity are favorable for root development and plant growth. Volcanic soils represent an important resource for agriculture in various world regions due to their unique properties, placing them among the most productive soils in the world. They are generally located in regions of high population density (Prado *et al.*, 2007).

Humid climate intensify the weathering of original materials, therefore the rate of soil formation and vegetation cover on volcanic material is high. Also elevation significantly affected soil properties, degree of soil weathering and density of vegetation cover, therefore soils at lower elevation is generally fertile and suitable for agriculture and soils at higher are

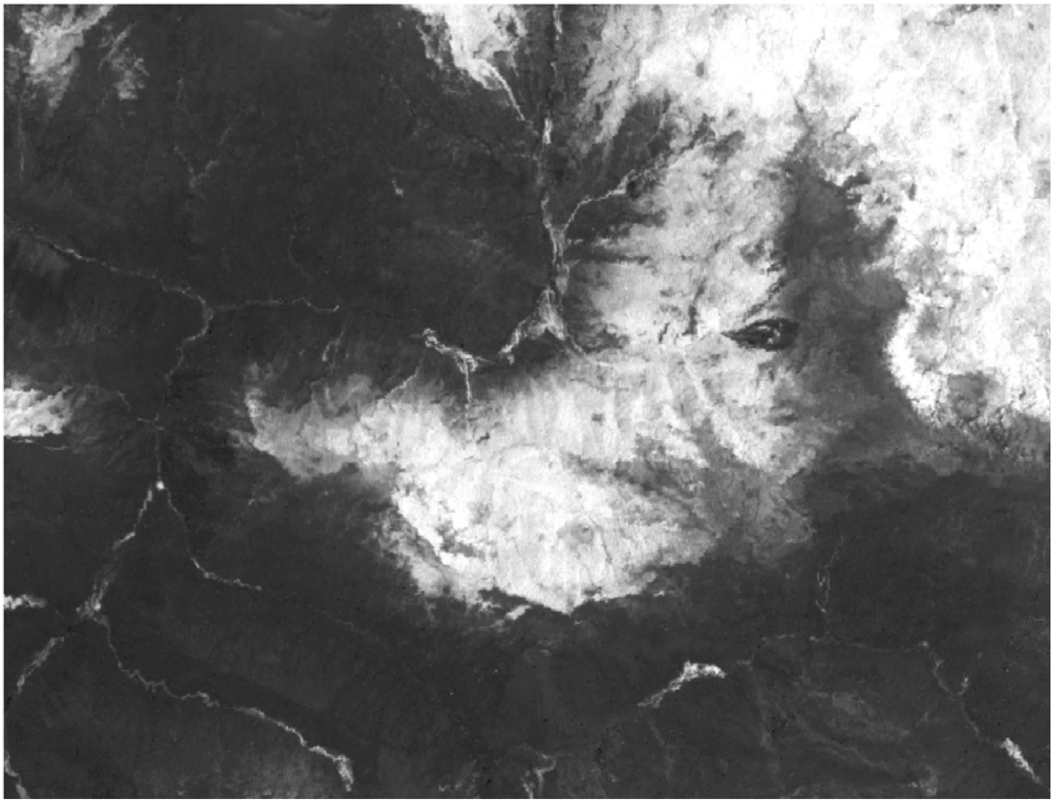

Fig.13. Normalized Difference Vegetation Index

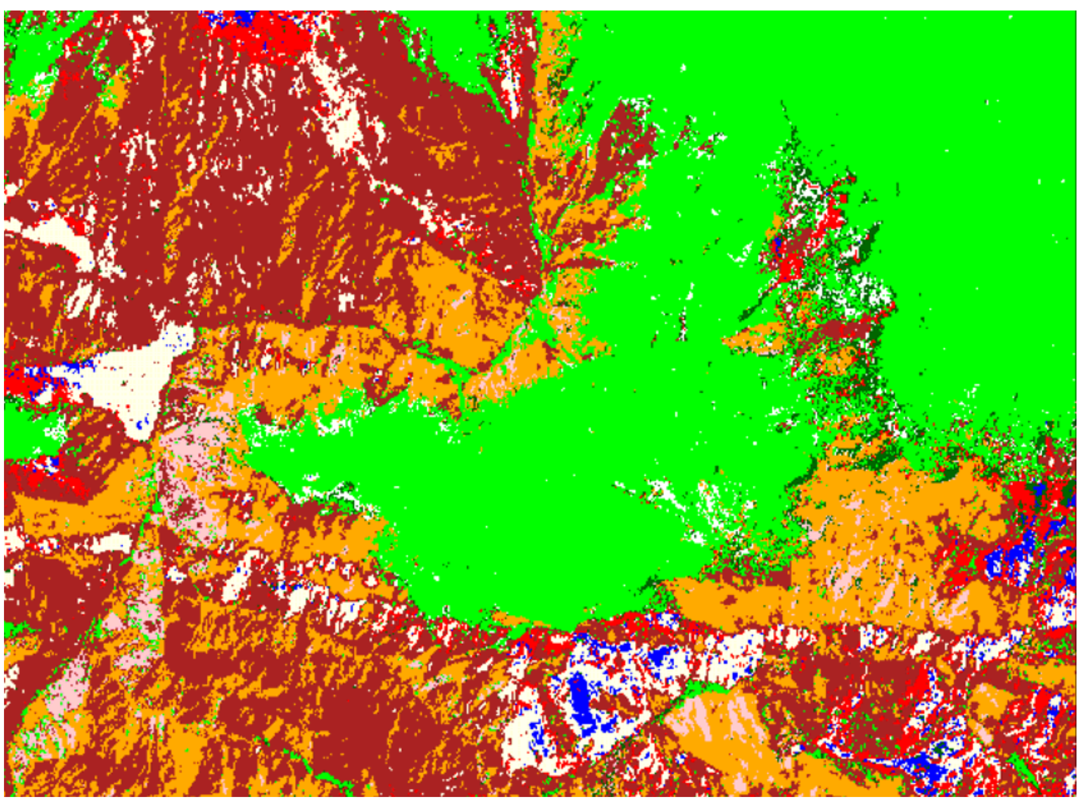

Fig. 14. Maximum likelihood classification

unsuitable for agriculture, and they are better used for forest and nature conservation. Beside in humid areas, limestone (particularly, dolomitic limestone) is less penetrated by water and therefore, not covered with vegetation.

We believe the units shown here are primarily differentiated from one another based on geomorphic / geologic in origin and not simply vegetative.

Satellite images are classified by different methods. In this technique pixels are assigned in groups based on their spectral properties (Ranjbar *et al.*, 2004) .A total of 11 lithological classes, including andesite, basalt, limestone, gypsum, sandstone and vegetation were chosen for the spectral classification.The methods selected include two statistical classification methods: *Minimum distance classification compares*: Minimum distance classification is attractive because it requires only a simple calculation and a relatively small number of training samples.

Maximum likelihood classification: Maximum likelihood classification is one of the most common supervised classification methods (Fig. 14). It has been suggested that the minimum number of training samples must be ten to 100 times the number of bands (Chen *et al.*, 2007).

CONCLUSION

- The false color composite Landsat TM images are most-suitable for regional structural analysis.
- The ratio images are used in lithological discrimination of different rock types as well as the alteration zones in the study area.
- Principal component analysis is widely used for mapping of alteration in this area.
- Faults and lineaments of the Siyah Bishe area were located in two groups according to their directions: one NE–SW and the other, NW–SE.
- The best exploration results are obtained by combining alteration and fracture mapping with the recognition of hydrothermally altered rocks.
- Volcanic rock clearly provides favorable conditions for hydrothermal water circulation and, therefore, mineralization with the presence of border faults and highly porous rocks such as andesites.
- Vegetation is an indicator of certain lithologic units, and is interrelated with water penetration and susceptibility to erosion.
- Remote sensing is no substitute for field mapping. We do not advocate remote sensing as a substitute for field mapping. Additional research and development is needed for remote detection of mineral deposits in vegetated terrain. These field studies were followed up with detailed petrographic and geochemical studies, in which rock types and structural associations were verified and reported.

ACKNOWLEDGEMENTS

The authors wish to thank the Kavoshgaran Engineering Adviser Society for financial support and for permission to use the data.

REFERENCES

Alaa, K. K. (2006). Tectonic architecture through Landsat-7 ETM+/SRTM DEM-derived lineaments and relationship to the hydro geologic setting in Siva region, NW Egypt. African Earth Sciences, **45**, 467–477.

Allenbach, P. (1963). Geology and Petrography of Mt. *Damavand* and Its Environment (Central Alborz), Iran. Tehran: Geological Survey of Iran

Chen, X., Warner, T. A. and Campagna, D. (2007). Integrating visible, near-infrared and short-wave infrared hyperspectral and multispectral thermal imagery for geological mapping at Cuprite. Remote Sensing of Environment, **110**, 344-356.

Chernicoff, C., Richards, J. and Zappettini, E. (2002). Crustal lineament control on magmatism and mineralization in northwestern Argentina: geological, geophysical, and remote sensing evidence. Ore Geology Reviews, **3**, 127-155.

Ehsani, A . H. and Quiel, F. (2010). Efficiency of Landsat ETM+ Thermal Band for Land Cover Classification of the Biosphere Reserve Eastern Carpathians, (Central Europe) Using SMAP and ML Algorithms. Int. J. Environ. Res., **4 (4)**, 741-750.

Grandjean, G. Paillou, P., Baghdadi, N., Heggy, E., August, T. and Lasne, Y. (2006). Surface and subsurface structural mapping using low frequency radar A synthesis of the Mauritanian and Egyptian experiments. Elsevier, Journal of African Earth Sciences, **44**, 220-228.

Kouli, M. and Seymour, K. (2006). Contribution of remote sensing techniques to the identification and characterization of Miocene calderas, Lesvos Island, Aegean Sea, Hellas. Geomorphology, **77**, 1-16.

Monavari , S. M. and Momen Bellah Fard, S. (2010). A GIS Based Assessment Tool for Biodiversity Conservation. Int. J. Environ. Res., **4 (4)**, 701-712.

Novak, I. and Soulakellis, N. (2000). Identifying geomorphic features using LANDSAT-5r/TM data processing techniques on Lesvos, Greece. Geomorphology, **34**, 101-109.

Pijanowski, B. C., Tayyebi, A., Delavar, M. R. and Yazdanpanah, M. J. (2009). Urban Expansion Simulation Using Geospatial Information System and Artificial Neural Networks. Int. J. Environ. Res., **3 (4)**, 493-502.

Prado, B., Duwig, C., Hidalgo, C., Gómez, D., Yee, C., Prat, C., Esteves, M. and Etchevers, J. D. (2007). Characterization, functioning and classification of two volcanic soil profiles under different land uses in Central Mexico. Geoderma, **139**, 300-313.

Ramadan, T. and Kontny, A. (2003). Mineralogical and structural characterization of alteration zones detected by orbital remote sensing at Shalatein District, SE Desert, Egypt. Journal of African Earth Sciences, **40**, 89–99.

Ranjbar, H., Honarmand, M. and Moezifar, Z. (2004). Application of the Crosta technique for porphyry copper alteration mapping, using ETM data in the southern part of the Iranian volcanic sedimentary belt. Journal of Asian Earth Sciences, **24**, 237-243.

Sabins, F. (1999). Remote sensing for mineral exploration, Remote Sensing Enterprises. Ore Geology Reviews, **14**, 157-183.

Sadati, N. (2009). Geochemical exploration of copper and related paragensis mineralization in Siyah Bisheh to Panjab area (Central Alborz), with emphasis on remote sensing data. Faculty of Earth Sciences, Shahid Beheshti University. MSC thesis. Unpublished, 182p.

Saintot, A., Angelier, J. and Chorowicz, J. (2000). Tectonic paleostress fields and structural evolution of the NW-Caucasus fold-and-thrust belt from Late Cretaceous to Quaternary. Tectonophysics, **357**, 1-31.

Solomon, S. and Ghebreab, Gh. (2006), Lineament characterization and their tectonic significance using Landsat TM data and field studies in the central highlands of Eritrea. Journal of African Earth Sciences, **46**, 371-378.

Thurmond, A., Abdelsalam, M. and Thurmond, J. (2006). Optical-radar-DEM remote sensing data integration for geological mapping in the Afar Depression, Ethiopia. Journal of African Earth Sciences, **44**, 119-134.