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Separation of geochemical anomalies using inverse distant weighting (IDW) and concentration-area (C-A) fractal modeling based on stream sediments data in Janja Region, SE Iran

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Research Article

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ABSTRACT

In this study, the Inverse Distant Weighting (IDW) and the Concentration –area (C-A) fractal methods were used for identifications of geochemical anomalies in Janja region, SE Iran. Eight elements (Au, Cu, Mn, Zn, Fe, As, Mo, and Pb) from 300 stream sediment samples were used. The studied area was gridded by 250 m×250 m cells. Estimation of unsampled locations were carried out by inverse distant squared weighting (IDWS) method. Geochemical maps were generated. Log- log plots of cumulative frequency of elemental concentrations versus related areas were constructed. Threshold values were obtained by finding break points in the log-log plots. There were four geochemical populations for As, Fe, Mo, Pb and Zn and five geochemical populations for Au, Cu, and Mn. The resulted geochemical anomaly maps obtained from fractal modelling showed that Anomalies of Zn, Mo, Mn, Fe, Cu and As located in southeastern part of study area. There was a good correlation between faults and elementals anomalies. It can be concluded that mineralization occurred along the faults. There was a correlation between anomalies and sedimentary rocks (alluvium and recent alluvium sediments) in SE part of study area. Gold anomalies were located in the NW parts of the studied area. There was a strong relationship between the location of Au anomalies and fault systems in the NW parts of the studied area. Iron concentrations were sporadic and correspond to the sedimentary volcanic rock and turbidites.

1. Introduction

The regional geochemical exploration is important in order to reduce the wide area to small areas, reduce the costs and risks of investment. Identification of geochemical anomalies from the background is one of the most important tasks in exploration geochemical studies. For anomaly separation, statistical methods were used frequently. In spite of successfulness, these methods have some disadvantageous. These include, removing some of data as the outliers, not considering to the spatial distribution of data, not considering to the geometric shape of anomaly and having condition of following normal distribution for data.

There are many interpolation methods. One of the most widely used is the inverse distance weighted (IDW) method. Inverse distance weighting (IDW) interpolation method often are used prior to contouring data. The reason is that most contouring procedures need values on a regularly-spaced grid. IDW assumes that each input point has a local influence that diminishes with distance. It weights the points nearer to the processing cell greater than those further away. A specified number of points within a specified radius can be used to determine the output value of each location.

In recent years, fractal analysis method was considered as a useful tool for separating geochemical anomalies. Today, especially in Iran, geochemical exploration studies focused on the stream sediments. These studies in detailed exploration phase, have an important role for finding optimistic area in regional scale. The most important results from any exploration geochemical statistical analysis is the separating

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different anomalies from each other and determines the background value for every element in the study area.

Based on Euclidean geometry, the around physical objects can be defined as shapes without dimension, one, two, and three-dimension. In Euclidean geometry, the dimension can be an integer such as one, two, three, and so on; but there are some phenomena in the world that cannot be justified in the framework of Euclidean geometry. For example, there is no possibility to determine some phenomena or events, such as the roughness of the surface of the mountains, shape of the coastline and many other natural objects and events by integer; also, the coordinate axes which are defined for describing these phenomena and events may not be perpendicular (Dimri, 2000). According to a non-Euclidean viewpoint, some phenomena and events can be considered as a Rational number in some cases. In these cases, the dimension can be changed from zero to one, from one to two or more. This viewpoint was the basis of the Fractal Geometry which was established by Mandelbrot (1983).

Fractal methods were proposed by Mandelbrot for the first time in 1983. Since 1990, different methods for anomaly separation were proposed based on the fractal methods (Cheng et al., 1994; Cheng et al., 1999; Davis, 2002; Afzal et al., 2011; Daya, 2015*a*; Daya, 2015*b*; Daya and Afzal, 2015; Daya et al., 2017). Fractal concentration- area (C-A) method was first used by Cheng et al (1994). It is based on fractal behavior of geochemical distribution in nature. In every contour map, the enclosed area decreases when the value of the contour increases. This is also true for elemental concentration contour map. From these contours, an optimum threshold for anomaly separation can be found by using a log-log plot for the element concentration-area relation. This threshold corresponds to the sudden change in the log-log plot. Log–log plots in concentration- area fractal method is a proper tool for separating and decomposing geological phenomena such as rock types, alteration units and more importantly mineralization. Theoretical Fractal studies and recent studies in earth science show that some geological processes such as mineralization, sedimentation, deposition, volcanic eruptions, morphology, and others have the characteristics of self-resemblance. Therefore, it can be found some evidences for fractal dimension from these cases (Cheng, 1999).

In this study, the geochemical exploration data related to stream sediments of Janja region were processed. The Concentration –area fractal model was used for determining the geochemical anomalies in Janja region, SE Iran. Eight elements (Au, Cu, Mn, Zn, Fe, As, Mo, and Pb) from 300 stream sediment samples were used to identify geochemical anomalies.

2. Methodology

2.1. Inverse Distance Weighting (IDW) Method

Many interpolation methods have been developed. One of the simplest and most widely used is the inverse distance weighted (IDW) method. IDW is based on the spatial dependence, it can be assumed that estimated values are more similar to nearby values than to distant values. The inverse distance weighted method estimates the value z of a point P as a function of the z-values of the nearest n points. The more distant a point, the less it influences the estimate. The advantage of the IDW method is that it is intuitive and its implementation is straightforward. Its main disadvantage is related to the determination of the weights based only on the location and ignoring the variance of the values.

The assigned values to unknown points are calculated with a weighted average of the values available at the known points. The name given to this type of methods was motivated by the weighted average applied, since it resorts to the inverse of the distance to each known point when assigning weights.

In the current paper, the study area was gridded by 250 m×250 m cells. Estimation of unsampled locations were carried out by inverse distant weighting (IDW) method. Then primary geochemical maps were generated.

2.2. Concentration-Area Fractal Model

Cheng et al. (1994) proposed the concentration–area fractal model, which may be used for anomaly separation, as the following form:

$$K(\rho \leq t) \infty \rho^{-a1}; \quad \mathrm{K}(\mathrm{p} \geq)\ \mathrm{p}^{-a2}$$

Where $K(\rho)$ denotes the area with concentration values greater than the contour value ρ; t represents the threshold; and $a1$ and $a2$ are characteristic exponents. In the current study the following approach was used to calculate $K(\rho)$: $K(\rho)$ are the values obtained by box counting of elemental concentration values. By box counting, one superimposes grid with cells in the region. The area $K(\rho)$ for a given ρ is equal to the number of cells multiplied by cell area with concentration values greater than ρ. The breaks between straight-line segments on this plot and the corresponding values of ρ have been used as thresholds to separate geochemical values into different components, at the same time representing different causal factors, such as lithological differences and geochemical processes (Daya, 2015a; Daya, 2015b). Factors such as mineralizing events and surficial geochemical element concentrations are important to be considered (Goncalves et al., 1998; Lima et al., 2003; Daya, 2015*a*; Daya, 2015*b*; Daya and Afzal., 2015; Afzal et al., 2010).

3. Geological Setting of Janja Area

The studied area is near the Sefidabeh, a district of Poshtab of Zabol city. The oldest rocks of the region are sedimentary rocks with flyschfacies largely dispersed in the region. Igneous rocks of the study area are mainly in the form of dykes from the trend of East - West and North East - South West which penetrated in sedimentary rocks and they have changed the general trend of the rocks (Figure 1; Camp and Griffis, 1982).

The region has general east-west and NE-SW trends structures. These trends followed by the inclined collision of Lut plate with Neh complex at the end of Eocene, continue the compressing movements; and at the end of Oligocene, the pressure, as sliding-stretching movements, has appeared in line with some old breaks and a much younger coupled system. Upper Miocene right turning tectonics affecting of old systems of the area which are related to the closure of east Flysch basin of Iran (Eocene-Oligocene) creates suitable stretching spaces for discharging lava. Dikes in the studied area are visible in form of altered and non-altered porphyritic in texture (Griffis et al., 1977; 1978).

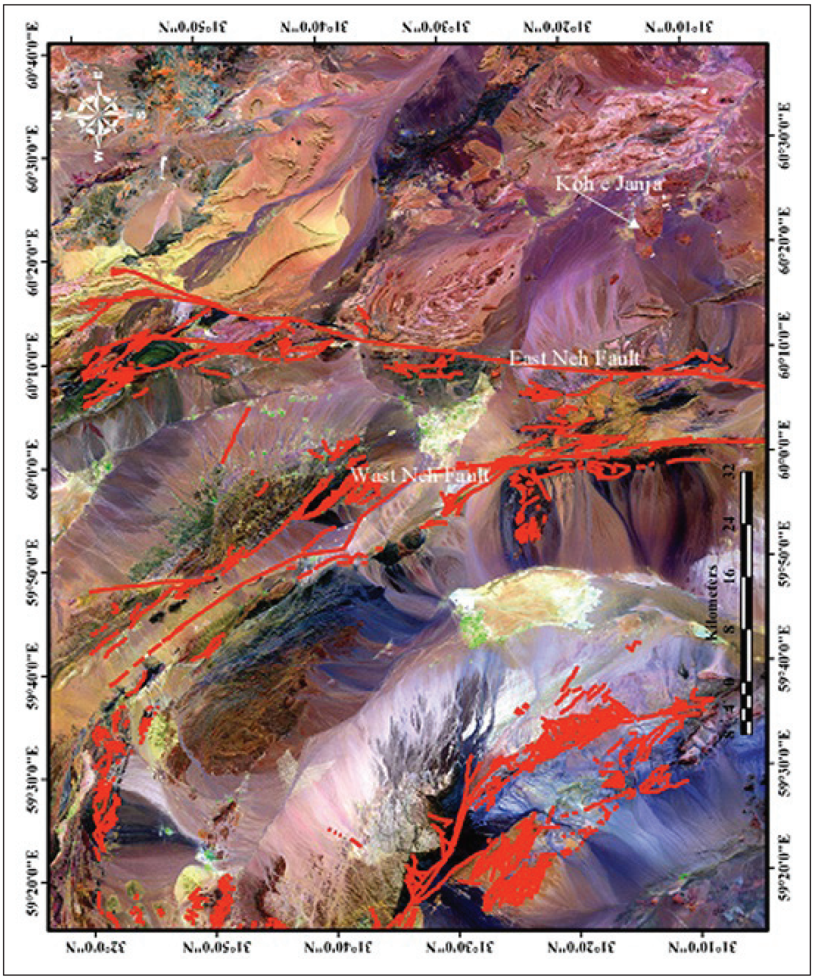

Figure 1- Janja regional satellite image that shows the main fault zone.

The main minerals of rocks in the region in hand specimen are amphibole (hornblende) and plagioclase (Figure 2). In addition to the main mineral in microscopic levels, there are secondary minerals of epidote, chlorite, calcite and opaque minerals. The results of the modal mineralogy studies and chemical analysis showed that these rocks are much more granodiorite to diorite in terms of lithological composition and they are in calc-alkaline range in terms of magmatic series.

Field investigations and laboratory studies that were done on igneous and metamorphic rocks showed that the studied region didn't have a lithological diversity. Igneous rocks are diorite dikes and sedimentary rocks include shale, sandstone and carbonate rocks (limestone and mudstone) which have undergone a weak transformation and heterology due to penetration dikes. These rocks along with dikes are form the highlands of this region. The metamorphic rocks in Janja region include slate and hornfels. It seems that protoliths of these rocks were carbonate shale and limestone which were undergone a weak transformation. It seems that in the last stages of the magmatic dikes cooling, hydrothermal fluids get out and at the time of penetrating the rock walls, it leads to the formation of minerals in them.

Potential mineralization in the area is done in two ways. The main form of mineralization in the area is associated with the transformation and alteration. The effect of this process include transforming the rocks, creating Calc-silicate rocks containing garnet, propillite alteration, making rocks siliceous, and the presence of sulfur minerals such as pyrite and chalcopyrite. The mineralization occurred as micro-riche fillings and the formation of iron oxides with copper carbonates (malachite and azurite) which were local and especially on the periphery of the main mineralization veinlets in form of low zones, show this kind of surface mineralization (Thomson and Howarth, 1978).

4. Sampling, Modeling and Data Analysis

In order to determine the anomaly area, the concentration of 8 elements of Au, Cu, Mn, Zn, Fe, As, Mo, and Pb in 300 points of region's stream sediments were measured and recorded. Figure 3 shows the location of sampling points in the studied region.

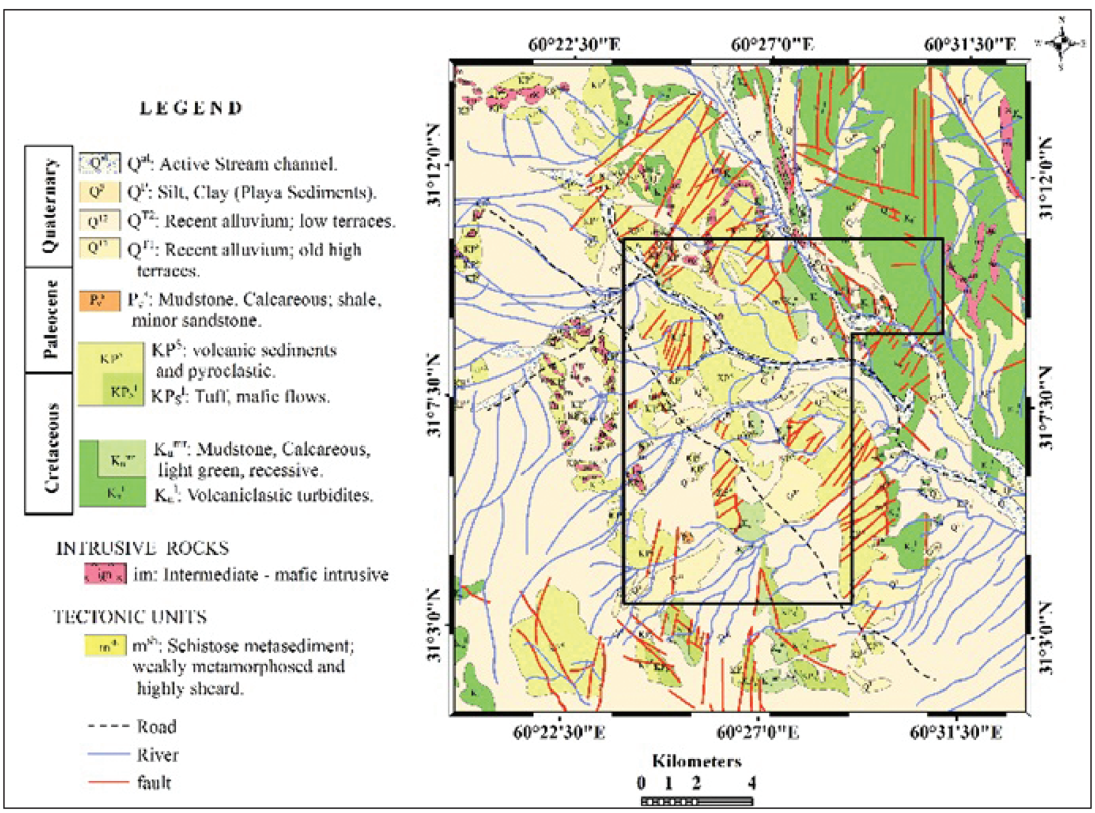

Figure 2- Geological map of Janja region with the scale of 1/20000.

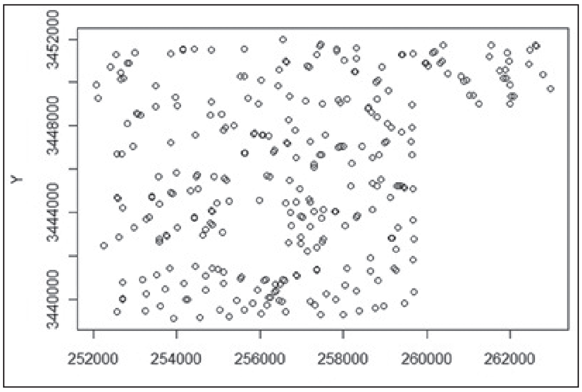

Figure 3- The location of stream sediments samples in Janja region.

The statistical investigation of collected data of stream sediment in the region in estimating and identifying the statistical features of the raw data, particularly the nature of their distribution function, help in better analysis of data resulting from estimation. Therefore, identifying the statistical variables of society including mean, variance, coefficient of variation, and in particular the skewness which implies on being normal or abnormal function of data distribution will be helpful (Jimenez-Espinosa et al., 1993). Statistical analysis was carried out by SPSS Statistical Software. In table 1, a summary of descriptive statistical observations is stated. Among all these factors, the shape of distribution function and its deviation from the normal distribution and the possibility of converting data to the normal distribution in the estimation process is very important (Jimenez-Espinosa et al., 1993). Therefore, it is necessary to draw a diagram and frequency distribution of data for these variables (Figure 4). In figure 4, to describe the data, histogram of variables is shown.

Statistical results revealed that mean values of As, Au, Cu, Fe, Mn, Mo, Pb and Zn were 15.34, 0.77,

Table 1- As, Au, Cu, Fe, Mn, Mo, Pb and Zn statistical parameters of 300 stream sediment samples from Janja region.

Element (ppm)	N	Min	Max	Mean	Std. Deviation
As	300	0.26	88.30	15.34	10.86
Au	300	0.01	3.00	0.77	0.49
Cu	300	0.12	133.12	22.43	14.16
Fe	300	174.0	88117.0	30127.61	16222.7
Mn	300	6.70	4063.05	822.10	520.90
Mo	300	0.01	5.93	0.89	0.61
Pb	300	0.20	378.20	67.60	53.05
Zn	300	0.92	435.71	64.27	43.45

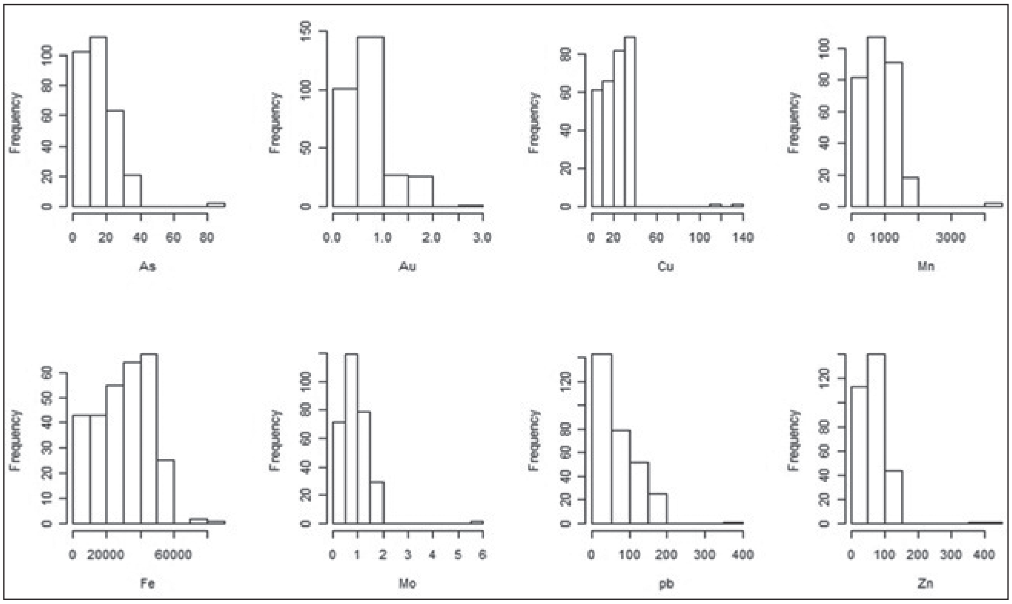

Figure 4- Histogram of As, Au, Cu, Mn, Fe, Mo, Pb and Zn in the stream sediment samples from Janja region.

22.43, 30127.61, 822.10, 0.89, 67.60, and 64.27 ppm, respectively. Their distributions are as shown in figure 4. Table 1 lists the statistical parameters of As, Au, Cu, Fe, Mn, Mo, Pb and Zn. Histograms of Mo, Mn and Fe appeared to be approximately symmetric. However, the histograms for other elements in the region do not show normal distributions.

To check the process, the diagram of data balance was plotted. The contour line is a curve that connects all the points with the same concentration. The reason of drawing the contour line of data is to see whether the mean of random field is constant or not. Figure 5 shows the contour lines curve for 8 studied elements. Since there isn't any special pattern in these figures, the mean of random field is considered as fixed.

5. Discussion

Geochemical maps were generated with Inverse Distance Weighing (IDW) method. IDW method was used for estimation. The maps were drawn by Rockworks software package. IDW method clarifies the concentration of region boundaries. It is more applicable and suitable to use Inverse Distance Weighing method rather than kriging. Kriging has high amounts of truncation errors for the upper and lower boundaries of region elemental concentrations (Afzal et al., 2010).

The studied area was gridded by 250 m×250 m cells. The proposed gridding pattern was applied because the principals of concentration- area fractal model was relied on the existence of partition function, and the sampled data could not be utilized efficiently; also, because one cannot sample the whole region, and for prediction of any parameter, i.e., elemental concentrations, gridding of the studied area was necessary and one cannot do otherwise (Afzal et al., 2010). The needed partition function to be applied in C-A fractal model is based on the assumption of having a cell characterization in the region in order to predict the area which has a special concentration. By this method the problem of over sampling will be solved because the concentration- fractal model automatically will remove any grid-related problem in division of the area into smaller elements and consequently; the original fractal character is preserved (Afzal et al., 2010).

5.1. Application of Concentration-Area (C-A) Fractal Model

Estimation of unsampled locations have been carried out by inverse distant squared weighting (IDWS) method. Then the elemental concentrations were sorted from low to high. Then the frequency of every element was calculated. Log- log plots of cumulative frequency of elemental concentrations versus related areas were drawn. Straight lines were fitted to the resulted log-log plots. There are a few break points in these plots. These are threshold values that separating populations of geochemical concentration. Figure 6 shows log-log plots for studied elements (Au, Cu, Zn, Fe, Mn, Mo, As and Pb) in the Janja region.

There are four geochemical populations for As, Fe, Mo, Pb and Zn and five geochemical populations for Au, Cu, and Mn as illustrated in figure 6. Based on the C-A log–log plot, there are four enrichment phases for As within threshold values equal to 14.15, 31.50 and 73.70 ppm where higher than the last threshold value the extreme As enrichment phase in the study area (Table 2). The population below 28282 ppm and between 32859 and 73130 ppm are the low and moderate phase of Fe enrichment, respectively. In addition, the population of upper than 73130 ppm has a high enrichment phase of Fe in the study area. Moreover, Cu C–A log–log plot shows five geochemical populations for this element with threshold values equal to 20, 28.5, 36.6, and 109 ppm (Table 2). Low and moderate Mn phases are below 812 ppm and between 1408 and 3294 ppm, but high phase has high value of Mn higher than 3827 ppm. Molybdenum has four enrichment phases in the study area based on Mo C–A log–log plot, as depicted in figure 6. Their threshold values equaled to 0.77, 1.50 and 4.95 ppm. Lower than 0.77 ppm is a low Mo enrichment phase in this area and moderate occurred between 1.50 and 4.95 ppm and population of upper than 4.95 ppm has a high enrichment phase of Mo (Table 2). Based on the results of the C–A model, the anomaly maps of every element were drawn (Figure 7, 8).

In figures 7 and 8, as shown in the right sidebar of maps, there is an increase in concentration as we go from yellow to red. In the other words, yellow means the backgrounds and the red shows the anomalies in that area.

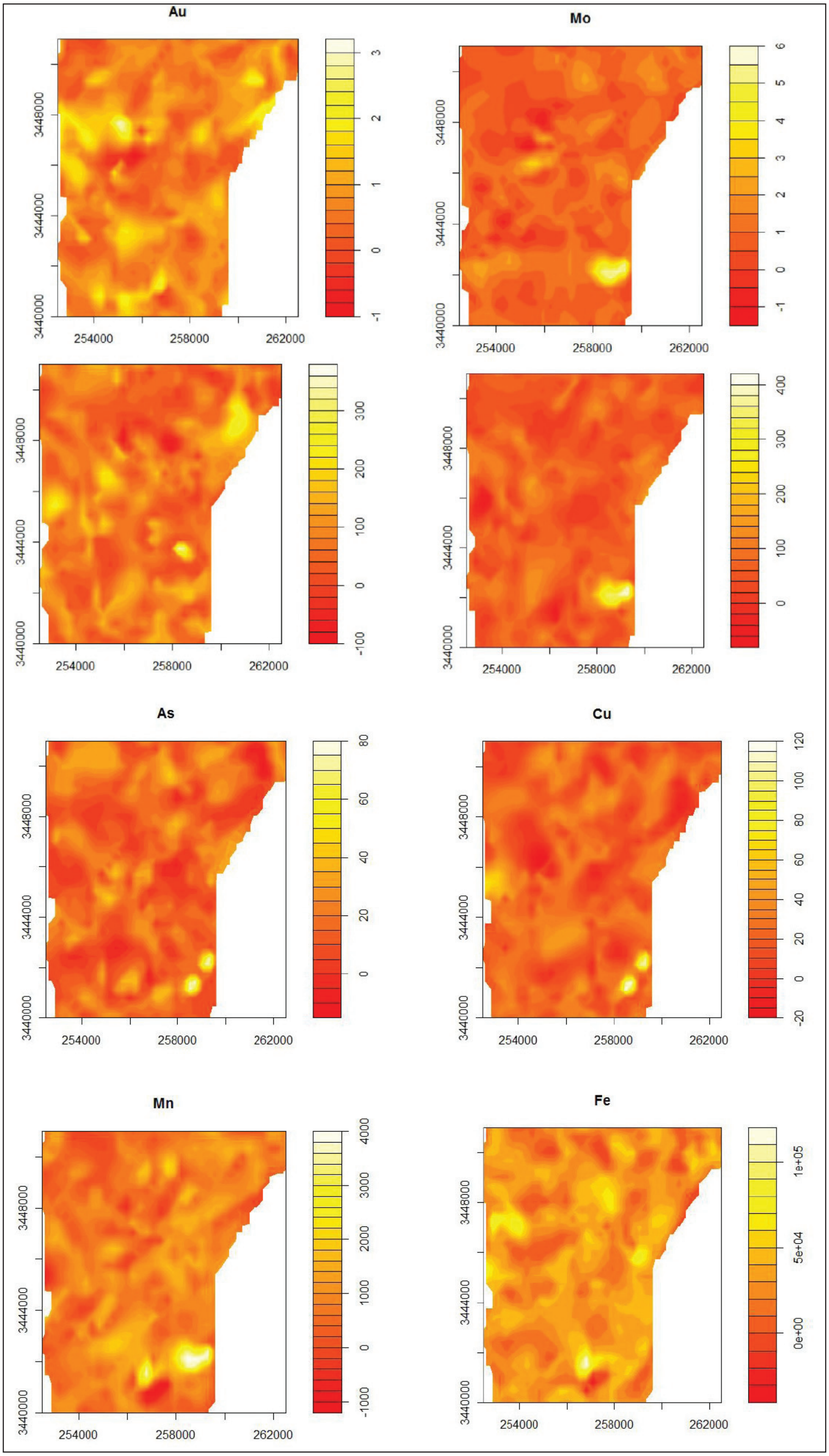

Figure 5- Contour line diagrams for 8 studied elements.

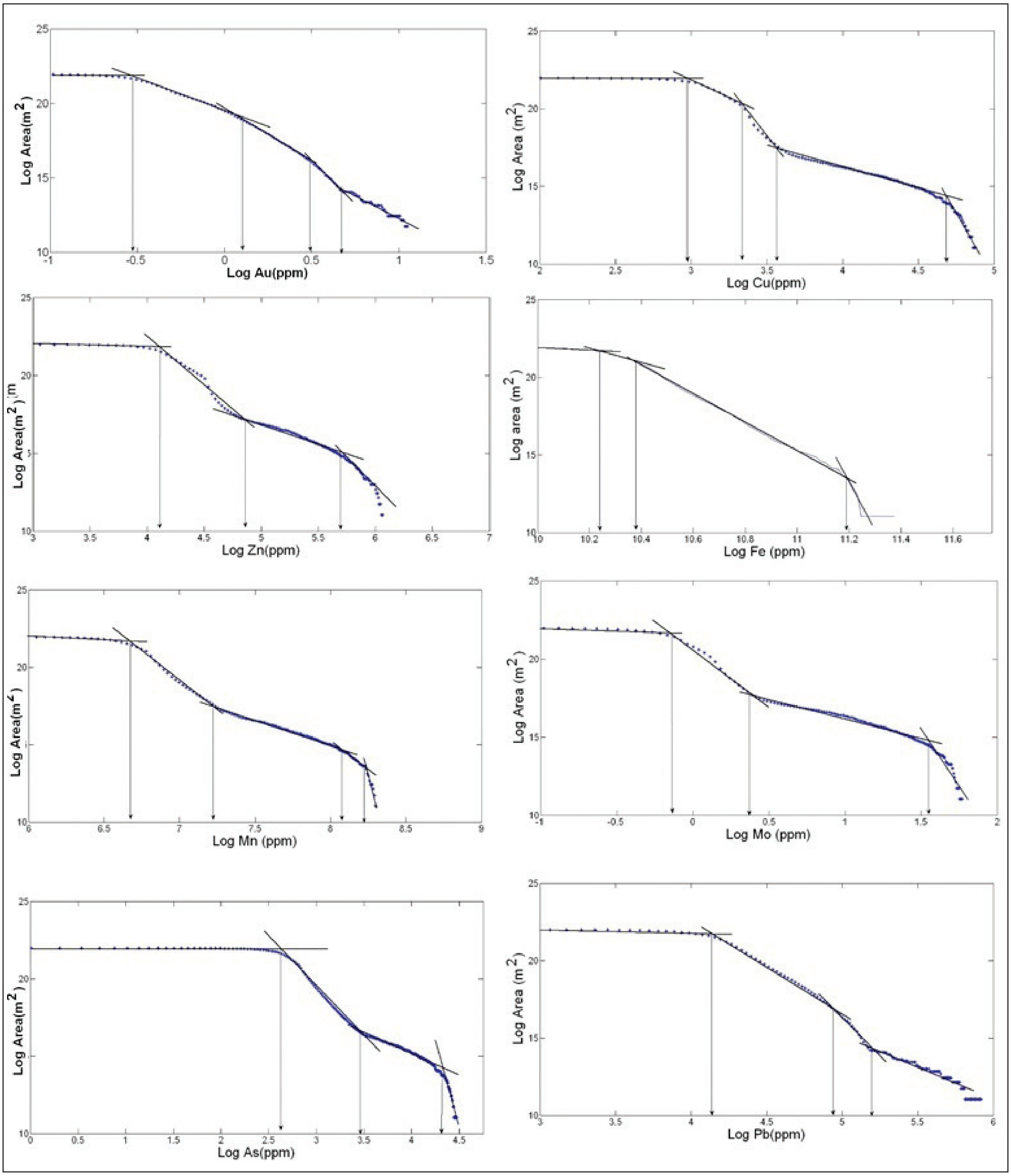

Figure 6- Log–log plots (C–A model) for Au, Cu, Zn, Fe, Mn, Mo, As and Pb.

5.2. Relationship Between Elemental Anomalies Resulted by C-A Fractal Model

By comparing the figure 7 and 8, it is concluded that concentration of elements has an inverse relationship with Au concentration, in a way that in the area in which the concentration of elements is high, the concentration of gold is low. It is observed that there is a direct correlation between the Fe anomalies and the Au anomalies (Figure 7). Therefore, using the magnetometry method can be a useful tool in determining the areas containing gold. By comparing figures 7 and 8, it is observed that there isn't any good correlation between manganese, lead, and zinc with

Table 2- Thresholds of C-A model for different geochemical anomalies of Au, Cu, Zn, Fe, Mn, Mo, As and Pb.

Element (ppm)	C-A fractal model		
	Low	**Moderate**	**High**
Au	0.60	1.16	1.65
Cu	20.10	28.50	36.6
Zn	61.56	121.50	284.30
Fe	28282.54	32859.63	73130.45
Mn	812.40	1408.10	3294.47
Mo	0.78	1.50	4.95
As	14.15	31.50	73.70
Pb	63.43	134.30	190.57

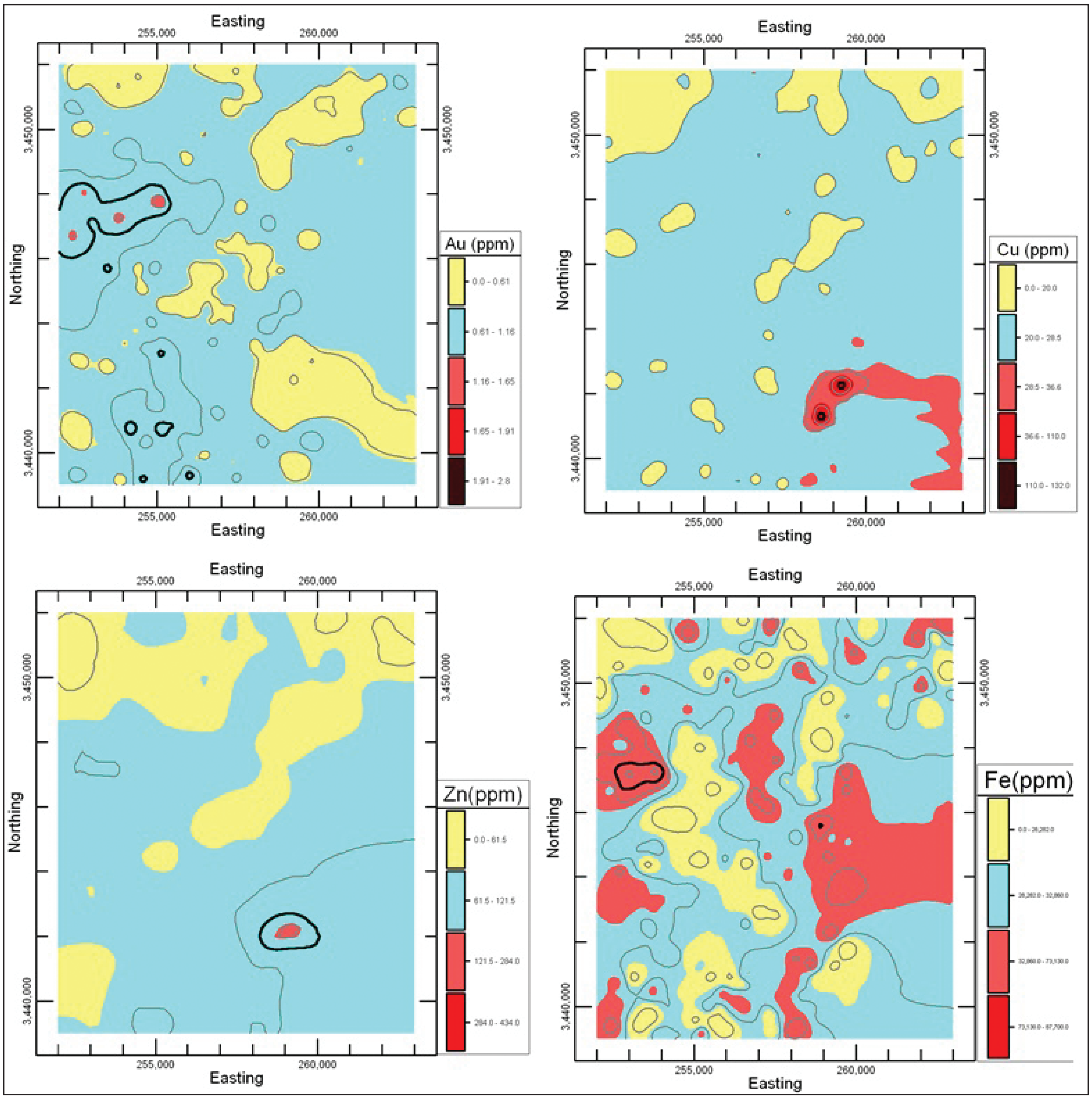

Figure 7- Au, Cu, Zn and Fe geochemical anomalies regions based on C–A model.

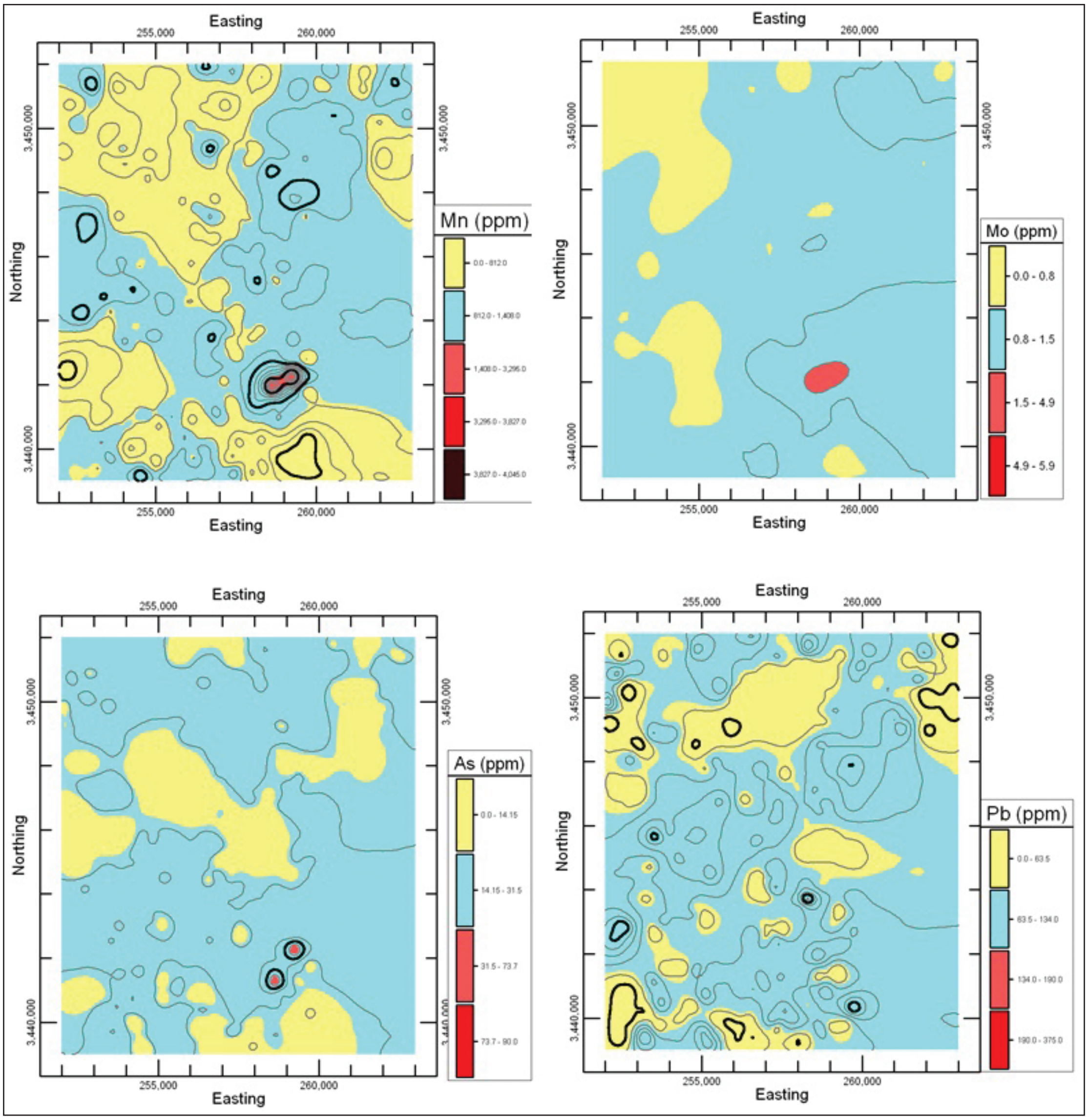

Figure 8- Mn, Mo, As and Pb geochemical anomalies regions based on C–A model.

gold. These elements cannot be a good guidance for determining the anomaly of gold in the region. Finally, the maps show that the correlation between the concentrations of molybdenum with copper is, to some extent, good. Given that the studied region is located within the mineral zone of Khash-Nehbandan, this area is the host of hydrothermal mineralization. The correlation between Cu, Zn, Mn, As, and molybdenum confirms this hydrothermal mineralization. Near this area, there is an antimony deposit of Sefidabeh. Totally, there is a correlation between the copper anomalies in the studied area with iron and molybdenum anomalies, which can be the proof of the porphyry origin of copper in this region; As it can be seen in figures7 and 8, the surface geochemical maps show the geochemical anomalies in southeastern part of area for Cu, Mo, Mn and As. It also can be seen in figure 2, the origin of this mineralization is likely a series of porphyry dykes with diorite composition, which have stopped the flyschfacies sedimentary units.

5.3. Correlation of Anomalies with Geological Process

Anomalies of Zn, Mo, Mn, Fe, Cu and As located in southeastern part of study area. Arsenic anomalies are accompanied with Cu and Mo anomalies. It can be said that As is a trace for mineralization. There is a good correlation between faults and elementals anomalies. It can be concluded that mineralization occurred along the faults. It can also be said that the type of mineralization is porphyry or vein type deposits. In most of the cases Cu and Mo mineralization are in porphyritic type and occurred in stockworks, veinlets and veins. The general trend of faults in this part of the studied are is northwest-south east (Figure2). There is an important point here that the strike of anomalies is the same as the strike of faults (Figs 7, 8, 2). It means that mineralization or enrichment are along the faults. Regarding lithology, there is a correlation between anomalies and sedimentary rocks (alluvium and recent alluvium sediments) in SE part of study area. These alluviums can be generated by weathering of volcanic and intrusive rocks. In addition, these anomalies correspond to the tuffs and turbidities in the SE part of the studied area. Gold anomalies are located in the NW parts of the studied area. There is a strong relationship between the location of Au anomalies and fault systems in the NW parts of the studied area. It can be interpreted that the gold mineralization occurred along the fault systems. The Gold anomalies are correlated to volcanic sedimentary rocks.

Iron concentrations are sporadic and correspond to the volcano-sedimentary rock and turbidites. There is a good correlation between the Fe anomalies and Faults in the study area. There is a direct relationship between Fe anomalies and Au anomalies in the NW part of the study area. Existence of Au and Fe anomalies in this part can be interpreted as the presence of hematization or limonitization alterations. As a result of these alterations Au enrichment occurred.

6. Conclusion

The concentration-area (C-A) fractal model is as a filter in geochemical prospecting when attempting to differentiate between anomalous samples and those belonging to geochemical background. In this study, this model was used for determining the anomaly map of eight elements in the studied area. The surface geochemical maps showed the existence of geochemical anomalies in southeastern part of the studied area for Zn, Mo, Mn, Cu and As. There are four geochemical populations for As, Fe, Mo, Pb and Zn and five geochemical populations for Au, Cu, and Mn. Except of the Iron anomaly, the anomalies of elements has an inverse relationship with Au concentration, in a way that in the area in which the concentrations of elements are high, the concentration of gold is low. The maps shows that the correlation between the anomalies of molybdenum with copper is, to some extent, good. Given that the studied region is located within the mineral zone of Khash-Nehbandan, this area is the host of hydrothermal mineralization, especially epithermal as well as the porphyry deposits. The surface geochemical maps show the geochemical anomalies in southeastern part of area for Cu, Mo, Mn and Arsenic. The origin of this mineralization is likely a series of porphyry dykes with diorite composition, which have stopped the flyschfacies sedimentary units. There is a good correlation between faults and elementals anomalies. It can be concluded that mineralization occurred along the faults. It can be said that the type of mineralization is porphyry or vein type deposits. There is a correlation between anomalies and sedimentary rocks (alluvium and recent alluvium sediments) in SE part of study area. Gold anomalies are located in the NW parts of the studied area. There is a strong relationship between the location of Au anomalies and fault systems in the NW parts of the studied area. It can be interpreted that the gold mineralization occurred along the fault systems. The gold anomalies are correlated to volcano-sedimentary rocks.

References

Afzal, P., Khakzad, A., Moarefvand, P., Rashidnejad Omran, N., Esfandiari, B., Fadakar Alghalandis, Y. 2010. Geochemical anomaly separation by multifractal modeling in Kahang (Gor Gor) porphyry system, Central Iran, Journal of Geochemical Exploration 104, 34–46.

Afzal P., Fadakar Alghalandis Y., Khakzad A., Moarefvand P., Rashidnejad Omran N. 2011. Delineation of mineralization zones in porphyry Cu 304 deposits by fractal concentration–volume modeling. Journal Geochemical Exploration 108, 220–232.

Camp, V.E., Griffis, R.J. 1982. Character, genesis and tectonic setting of igneous rocks in Sistan suture zone. Lithos, Vol.15, pp.21-239.

Cheng, Q. 1999. Spatial and scaling modeling for geochemical anomaly separation: Journal of Geochemical Exploration, 65,175–194.

Cheng, Q., Agterberg, F.P., Ballantyne, S.B. 1994. The separation of geochemical anomalies from background by fractal methods. Journal Geochemical Exploration 51,109–130.

Daya, A.A. 2015*a*. Comparative study of C–A, C–P, and N–S fractal methods for separating geochemical anomalies from background: A case study of Kamoshgaran region, northwest of Iran. Journal of Geochemical Exploration. 150: 52–63.

Daya, A.A. 2015*b*. Application of concentration–area method for separating geochemical anomalies from background: a case study of Shorabhaji region, northwest of Iran. Arabian Journal of Geosciences. 8:3905–3913.

Daya, A.A, Afzal, P. 2015. Comparative study of concentration-area (C-A) and spectrum-area (S-A) fractal models for separating geochemical anomalies in Shorabhaji region, NW Iran. Arabian Journal of Geosciences 8:8263–8275.

Daya, A.A., Boomeri, M., Mazraee. 2017. Identification of Geochemical Anomalies by Using of Concentration-Area (C-A) Fractal Model in Nakhilab Region, SE Iran. Journal of Mining and Mineral Engineering. 8,70-81.

Davis, John C. 2002. Statistics and Data Analysis in Geology, 3th ed. John Wiley & Sons Inc, New York.

Dimri, V. 2000. Application fractals in earth sciences: Springer- Verlag, New York.

Goncalves, M.A., Vairinho, M., Oliveira, V. 1998. Study of geochemical anomalies in Mombeja area using a multifractal methodology and geostatistics. In: Buccianti A, Nardi G, Potenza R (eds) IVIAMG'98. De Frede, Ischia Island, pp 590–595.

Griffis, R.J., Meixner, H.M., Griffis,A.T., Bondar, W.F, Leitch, C.H.B. 1977-1978. Report on preliminary mineral reconnaissance aest block, East Iran, *Geology and Mineral Survey of Iran.*

Lima, A., De Vivo, B., Cicchella, D., Cortini, M., Albanese, S. 2003. Multifractal IDW interpolation and fractal filtering method in environmental studies: an application on regional stream sediments of Campania region (Italy). Applied Geochemistry 18, 1853–1865.

Mandelbrot, B.B. 1983. The Fractal Geometry of Nature (Update and augmented edition), Freeman, New York, 468 pp.

Jimenez-Espinosa, R., Sousa, A.J., Chica-Olmo, M. 1993. Identification of geochemical anomalies using principal component analysis and factorial kriging analysis, Journal of Geochemical Exploration, 46, 245-256.

Thomson, M., Howarth, R.J. 1978. A new approach to the Estimation of Analytical precision, Journal of Geochemical Exploration, Vol.9.