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Separation of geochemical anomalies by concentration-area and concentration-number methods in the Saqez 1:100,000 sheet, Kurdistan

Fatemeh Zadmehr[1], Seyed Vahid Shahrokhi*[1]

1. Department of Geology, Factually of Science, Khorramabad Branch, Islamic Azad University, Khorramabad, Iran

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Abstract

Regional exploration and identification of anomalies can be done by geochemical data resulted from stream sediments. In this paper, fractal methods of concentration-number and concentration-area were used for regional studies, and abnormalities of elements including gold, arsenic, bismuth and mercury were studied. Statistical processing of these elements took place with the help of 1063 samples of stream sediments in the Saqez 1:100,000 sheet (Kurdistan Province). The elements were analyzed in the laboratory of the Geological Survey and Mineral Exploration of Iran by ICP-OES method and Au element was analyzed by Emission Spectrograph method. According to the position of geology, existing structures and the dominant rock type, the comparison between the map prepared methods of concentration-number and concentration-area was conducted in Saqez sheet. In general, the results of the two methods showed that in the south, southwest, center and west of the region, the concentration of these elements is increased, and presence of ore promising areas is high in these areas. Concentration-number method showed a good overlap with concentration-area method; making extensive geochemical halos and encompassing known ores of Qolqoleh, Kervian and Qabghlojeh, it follows the expected process of mineralization in Sanandaj-Sirjan zone.

Keywords: *Concentration-Area (C-A); Concentration-Number(C-N); multifractal modeling; Stream sediments; Saqez*

1. Introduction

Geochemical data of stream sediments are of great importance in regional exploratory studies, especially finding early anomalies and promising mineral areas. Interpretation of these data using fractals in recent years has really helped finding valuable mineral anomalies and promising areas of mineralization (Daneshvar Saeen et al. 2011; Meigoony 2013). In addition, there is a fractal relationship between the amount of cumulative storage in an ore and average concentrations of its different parts (Turcotte 1986). Many natural processes, especially processes related to geosciences, do not follow regular dimensions of Euclidian geometry; hence, geometry must be used to describe the events in nature. Accordingly, for the first time in 1983, the French Professor Benoit Mandelbrot presented a geometry based on which the processes found in nature could be discussed and examined; he called this geometry fractal (Mandelbrot 1983). For the first time, for the separation of geochemical anomalies and field from each other, Cheng et al. (1994) used concentration-area and concentration-perimeter on the ore on porphyries copper-gold (Mitchel-Sulphurets) in British Columbia, Canada (Cheng et al. 1994). In general, exploratory, particularly geochemical data have multifractral behavior; this shows the changes in geological, geochemical, alteration, surface weathering, and subsequently, enrichment and mineralization steps.
Comparing these with geological data and observations, the accuracy of these modelings is well understood (Afzal et al. 2013; Heidari et al. 2013; Hosseini et al. 2015).

2. Geography and Geology

Saqez 1:100,000 Geological sheet is located in the South East of square 1:250,000 of Mahabad in Kurdistan Province and a small part of West Azerbaijan province and in the northwest of the country. The geographical coordinates of this region are 46° 00′ to 46° 30′ East longitude and 36° 00′ to 36° 30′ northern latitude (Fig 1). According to the division of structural units (Stocklin 1968), this region is located in the northwestern part of the Sanandaj-Sirjan zone. The oldest rock units in the sheet of Saqez include a thick sequence of metamorphic rocks of gneiss, schist, marble and amphibolite which are attributed to Precambrian and covered with carbonatic-clastic sediments of the bottom Precambrian-Cambrian (dolomites of Soltanieh, shale and Barot of sandstone, Zaigon, Lalon and Mila) in an incompatible way; and they are more extended in East, South East and South West of the sheet. Permian deposits are located on the older rocks (mainly Mila Formation) with relatively wide spread and incompatible borders. They contain two red sandstone in the bottom (Doroud Formation equivalent) and thick gray layer limestone above (Ruteh and Nessen Formation equivalent). Deposits related to Jurassic are mainly consisting of sequences of thin shale and sandstone of green-gray layer (Shemshak Formation sediment equivalent) that is located on Triassic dolomite or older rocks in an inconsistent way. After that, relatively thick Cretaceous units will include gray pencil

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*Corresponding author.
E-mail address (es): Vahid.Shahrokhi@Gmail.com

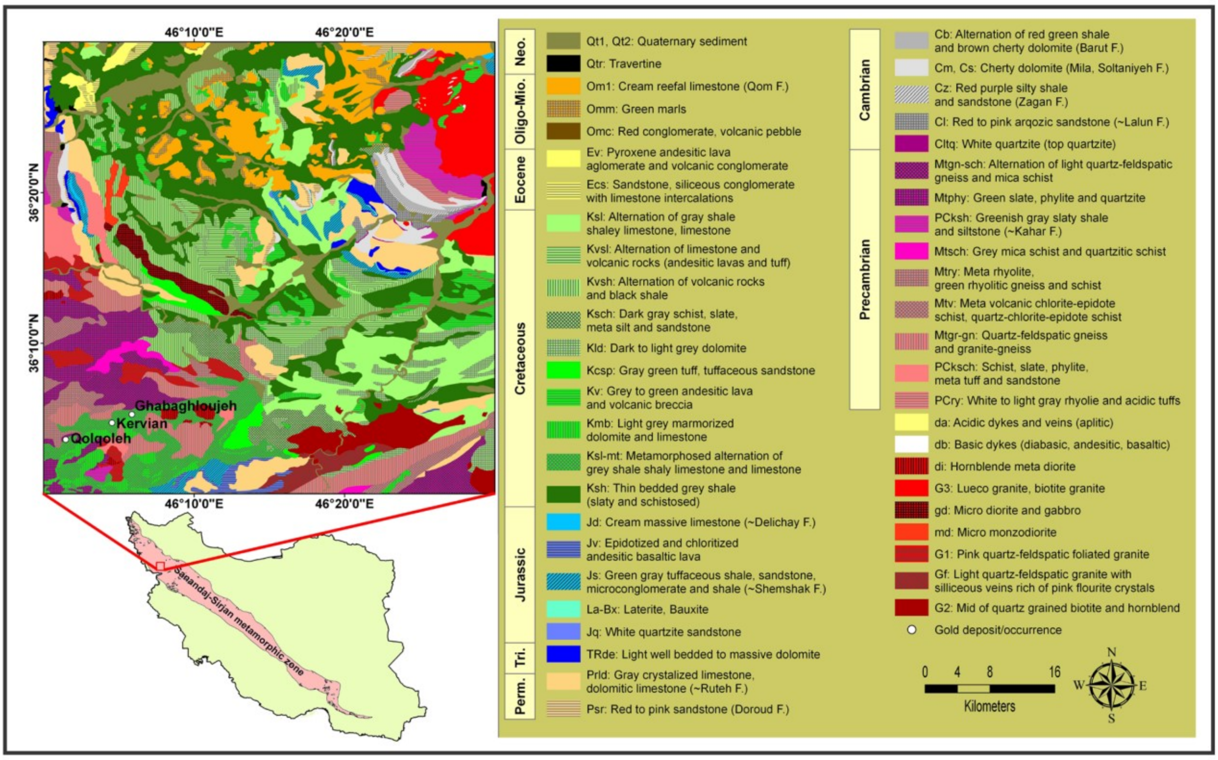

Fig 1. Saqez geological map (1:100000 scale: after Babakhani et al., 2003)

calcareous and silty shales, shale and limestone sequence, thick layers of limestone and dolomitic limestone will appear. Eocene rock units also include a conglomerate, sandstone and limestone collection below, and a green lava set and cutting tuff with andesitic combination, and between limestone and conglomerate layers above which lead to carbonate sediments and siliciclastic Oligo-Miocene and quaternary deposits. Important mineralization of this sheet includes gold of Qolqoleh, Kervian and Qabaghloujeh, Hamzaqarnain, Kaniparri, Piromran which are of Mesothermal gold ores associated with vein quartz type (Monecke et al. 2005; Shahrokhi 2008; Aliyari et al 2009; Shahrokhi et al. 2009; Afzal et al 2013; Shahrokhi and Zarei-Sahamieh 2013; Hosseini et al. 2015) (Fig 1).

In the range of Sagez sheet, a series of intrusive masses have granite, granodiorite monzonite, diorite, and gabbro having periodic changes of Precambrian to Tertiary and cut off various rock units of Precambrian to Cretaceous (Shahrokhi and Zarei-Sahamieh 2013). The granite sections of these masses are divided into three units of G1, G2, and G3, in which the subtractions dependent on them in Sagez sheet are separated from each other Md, Gf, etc. Medium sections are defined as diorite, gabbro, and monzodiorite masses (Shahrokhi et al. 2009).

Metamorphism is considered as the most important factor in the overall formation of the Sagez region, which has operated in three regional, adjacent and dynamic forms. Units derived from the regional metamorphism include amphibolite facies, gniss to green schist, and rocky units derived from adjacent metamorphism include hornfels units, andalusite schist to cordierite schist (Shahrokhi 2008). The extreme metamorphism of the Precambrian metamorphic complex and their incompatible boundaries with the deposits of underneath Precambrian-Cambrian, as well as intense magma activity along with the intrusive mass of the Earth, represent the late Precambrian tectonic-orogenic movements in the region (Babakhani 2003). From the point of view of structural geology, the study area is a crushed and tectonized area whose general structure is formed as a deformable deformation (China), as well as various abutments and faults due to the severity of pressure. Conformity of most of the rock units in the range of Sagez sheet is often as faults and tectonized (Shahrokhi 2008), and in general, they can be placed in three main sets according to the trends they take. The first group contains the faults of Northwest-Southwest trend including major thrust faults in the region that are parallel to the main trend of Zagros.

These faults lead to the drift of older classes on younger classes, and sometimes their trend changes locally. The second group contains the Northeast-Southwest trend to

Paleocene epoch, which has numerous fractures and faults in the region, and most of them are trusts that can be traced by this trend similar to the main trusts (Northwest-Southeast) (Eftekharnejad 1980). The third group is the network of faults that do not follow a specific trend and can be seen around annular buildings that are likely to be affected by the penetration of intrusive masses (Kheiri 1998) (Fig 2).

The northern part of the SSZ hosts numerous mineralogy types of magmatic masses of gold, golden-carlin, and orogenic and mesothermal gold deposits (Shahrokhi et al. 2009). The mineralogy associate with intrusive bodies rocks that accompany with Cretaceous felsic pyroclastic sequences. Especially in the center of the study area, the Cretaceous units have the highest distribution in the East and West regions of the region with intrusive masses (Shahrokhi 2008). Known gold-silver-copper mineralization in Barika with Korko type, with dominant meta-andesite lithology and tuff and with the rock of the host of Cretaceous meta-volcanics (Monecke et al. 2005; Yarmohammadi et al 2008; Afzal et al. 2013; Makovicky et al 2013; Heidari et al. 2013; Hosseini et al. 2015). And in the construction site, they are flexible, fragile and quartz-vein type.

Fig 2. Structural map of Saqez 1:100,000 sheet

3. Materials and Methods

3.1 Preparation of exploratory data

In the Saqez 1:100,000 sheet, 1063 geochemical samples of stream sediment were collected (Fig 3). For optimum use of data from each sample, it was tried to consider the samples distribution in mountainous areas less than a kilometer along the stream. Of course, the coverage of each sample must have a suitable condition for network estimation.

Preparation was done by dissolution in four acids; Au element was analyzed by Emission Spectrograph method, and other elements were analyzed using atomic absorption and ICP (OES) methods. To determine the feasibility of using fractal methods for geochemical anomaly separation, we can use single-element Q-Q plot. This lot identifies breakpoints of geochemical populations. Q-Q plot shows several geochemical populations for elements of Au, As, Bi, and Hg, that indicates the mixture and different geological and geochemical processes, and suitability of the fractal method for separation of geochemical anomalies in the study area (Zuo et al. 2009; Zuo 2011) (Fig 4)

3.2. Classification, distribution and statistical parameters of data

One of the most important parts of any project is documentation raw information and data of the project. In this project, documentation of numerical data from samples' analysis is done in the environment of Excel software while documentation of the map data is conducted in the ArcGIS software environment.

Samples histogram plot (element frequency or measurement factor) was also drawn. Elements distribution histograms were prepared for Sagez area as can be observed in Figure 5. Distribution of copper in this sheet closer to the normal distribution compared to other elements.

Gold shows a single-community distribution, but other elements are more similar to L distribution. The most important statistical parameters used in the interpretation of data include mean, median, skewness, elongation, maximum, minimum, variance and standard deviation; these parameters were calculated for the elements of gold, arsenic, bismuth and mercury. The statistical parameters are given in Table 1 for these elements and for separation of anomaly communities from the field. Threshold limit for gold, arsenic, bismuth, and mercury are 1, 0.5, 0.2, and 0.1, respectively.

4. Discussion

4.1. Area-concentration fractal method

Area-concentration fractal method presented by Cheng et al. (1994) is based on the area occupied by each certain concentration in the region under study, presented by a series of simple empirical equations. This experimental model suggests that area of $A(\rho)$ in addition to the values of concentration ρ is less or equal to a predetermined threshold value of υ follows the exponential relationship below:

$A(\rho \leq \upsilon) \propto \rho^{-\alpha_1}$; $A(\rho \leq \upsilon) \propto \rho^{-\alpha_2}$

Where A (ρ) is the area with concentration higher than P equivalent curve, and υ indicates the threshold limit, and α1 and α2 are identical powers.

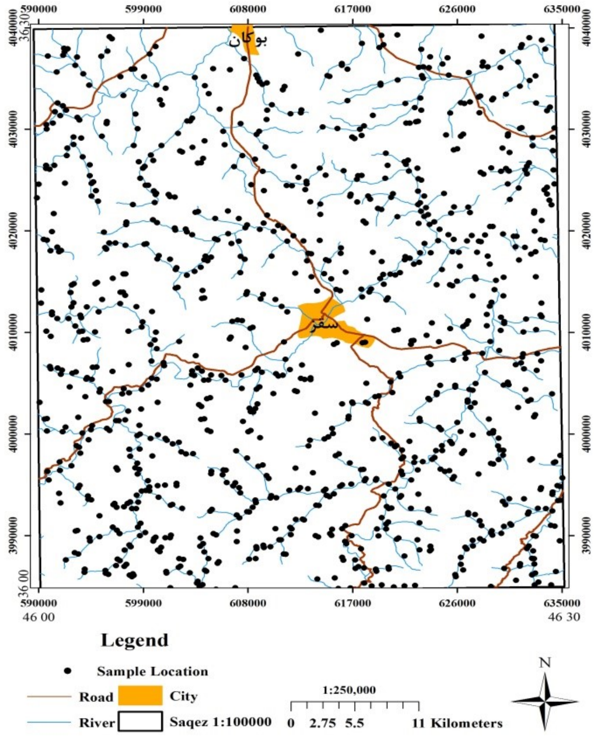

Fig 3. Samples map of the stream sediment in Sagez 1:100,000 sheet

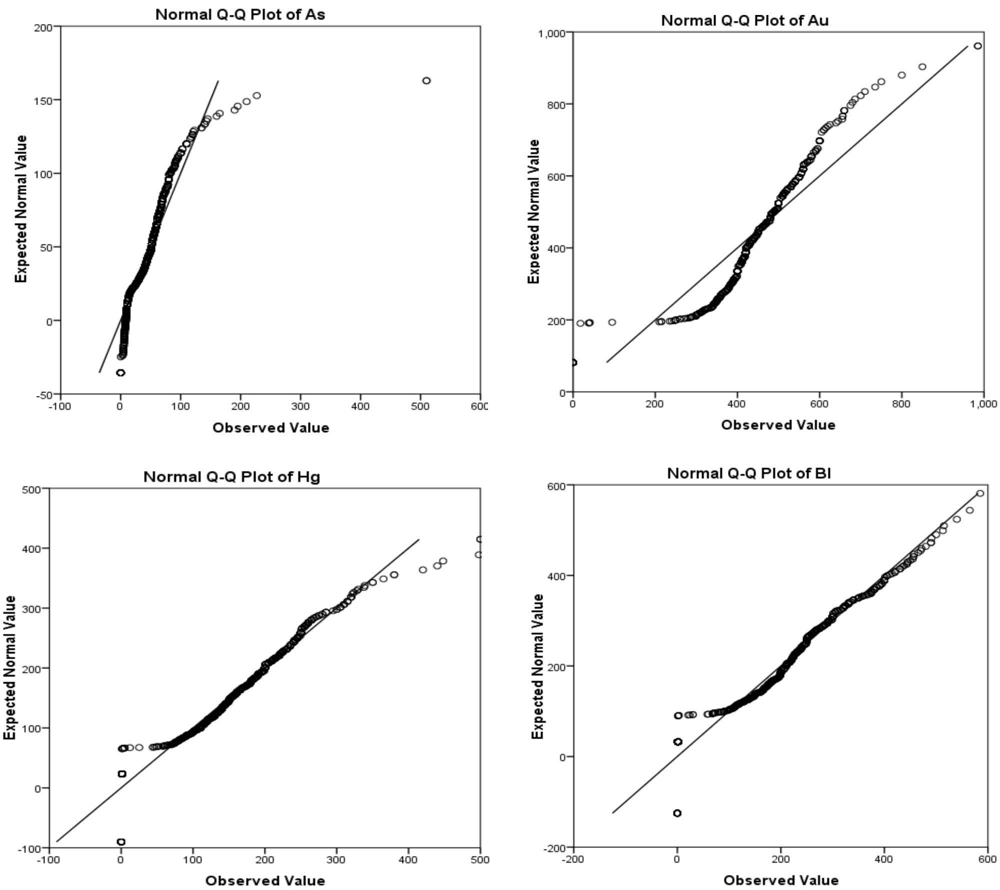

Fig 4. Q-Q plot of raw geochemical data of elements Au, As, Hg and Bi

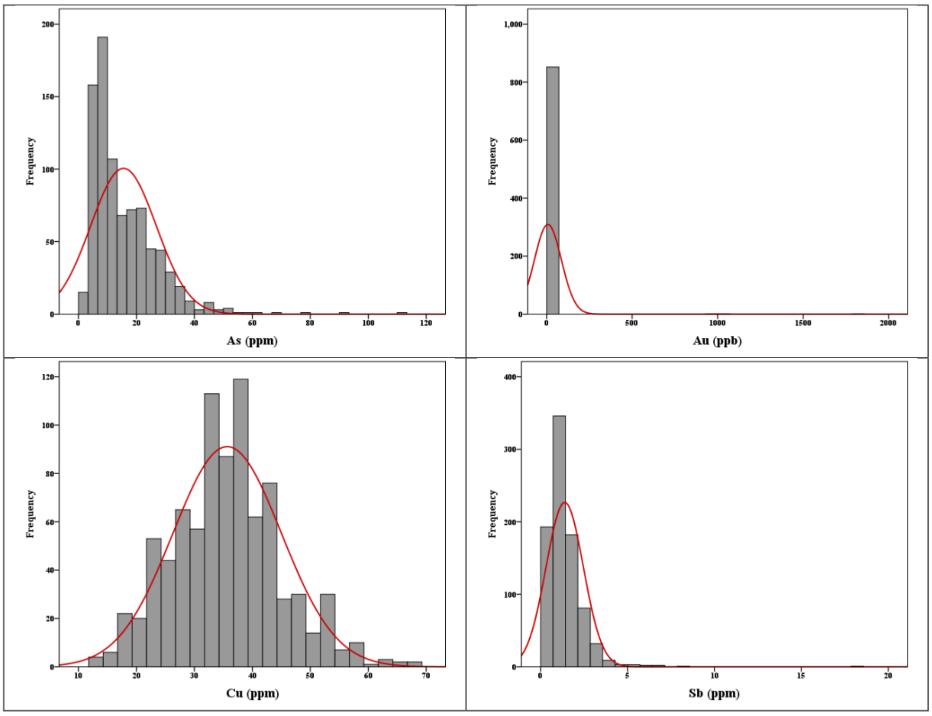

Fig 5. Histogram of gold, arsenic, bismuth and mercury in Saqez sheet

Table 1: Statistical parameters and results of the elements of gold, arsenic, bismuth and mercury in Saqez sheet

Element	Mean	Median	SD	Variance	Skewness	Kurtosis
Gold(ppb)	311.99	391	214.87	306	0.881	-0.168
Arsenic(ppm)	49.26	51	34.3	16772	3.54	9.75
Bismuth(ppm)	168.4	185	129.7	1560.2	0.17	-0.416
Mercury(ppm)	124.72	135	95.74	9177.6	0.295	-0.213

4.2. Concentration-number fractal method

This method is based on inverse relationship between concentration and cumulative frequency of each concentration and higher concentrations. This method is presented based on the following formula (Mao et al. 2004):

$N(\geq C) \propto \rho^{-\beta}$

In the above equation, N (≥C) is the number of examples that is equal and higher than C. ρ is the concentration and β is the fractal dimension.

4.3. Preparation of maps introducing elements abnormalities by concentration-area and concentration-number fractal methods

The important advantage of this method is that it conducts the calculations before estimation using raw explorative data. Fractal methods can explain the relationship between the results of geological, geochemical and mineralogical studies. The logarithmic graphs of concentration-area fractal method suggest the changes and geological differences. Breaks between the pieces of the straight line on the graph and the values corresponding to the element concentration of ρ are used as the threshold limits for separation of geochemical values among the various components representing a variety of factors, including geochemical processes and lithological differences.

Four-element fractal curves were drawn first (Fig 6 and 7), and then, distribution maps of these elements were drawn by ArcGIS software (Fig 8 and 9). Data estimation was performed using inverse square distance. Table 2 shows the various anomalies threshold limits of the elements based on concentration-area fractal method. Based on logarithmic graphs in the element of gold, two geochemical communities can be seen, while for arsenic and mercury, we can see three geochemical communities, and four for bismuth.

Table 2. Threshold limits of gold, arsenic, bismuth and mercury using concentration-area in Saqez sheet

Element	Background limit	Aanomaly limit	High anomaly limit
Gold (ppb)	≤316.22	≤316.23	---
Arsenic (ppm)	≤50.11	≤100.9	≥ 100.17
Bismuth (ppm)	≤125	≤223.8	>316.22
Mercury (ppm)	≤100	≤177.8	>177.9

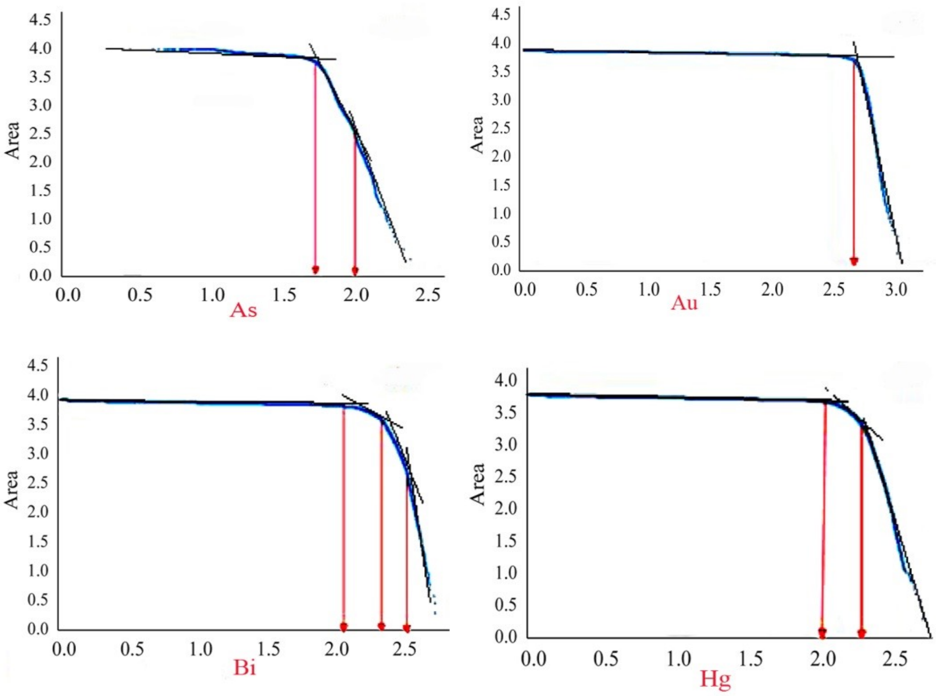

Fig 6. Concentration-area logarithmic graphs of gold, arsenic, bismuth and mercury in Saqez sheet

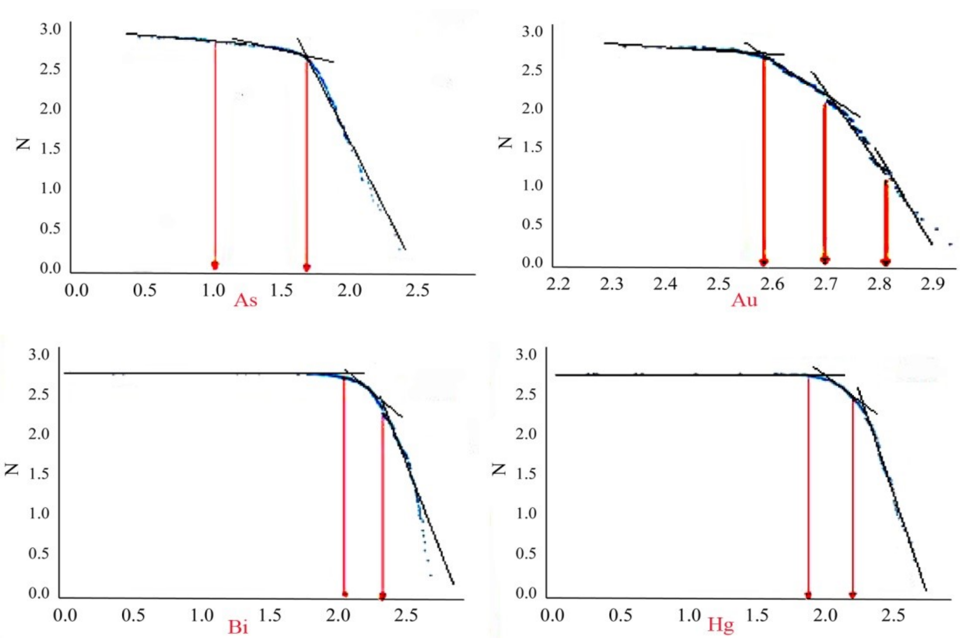

Fig 7. Concentration-number logarithmic graphs of gold, arsenic, bismuth and mercury in Saqez sheet

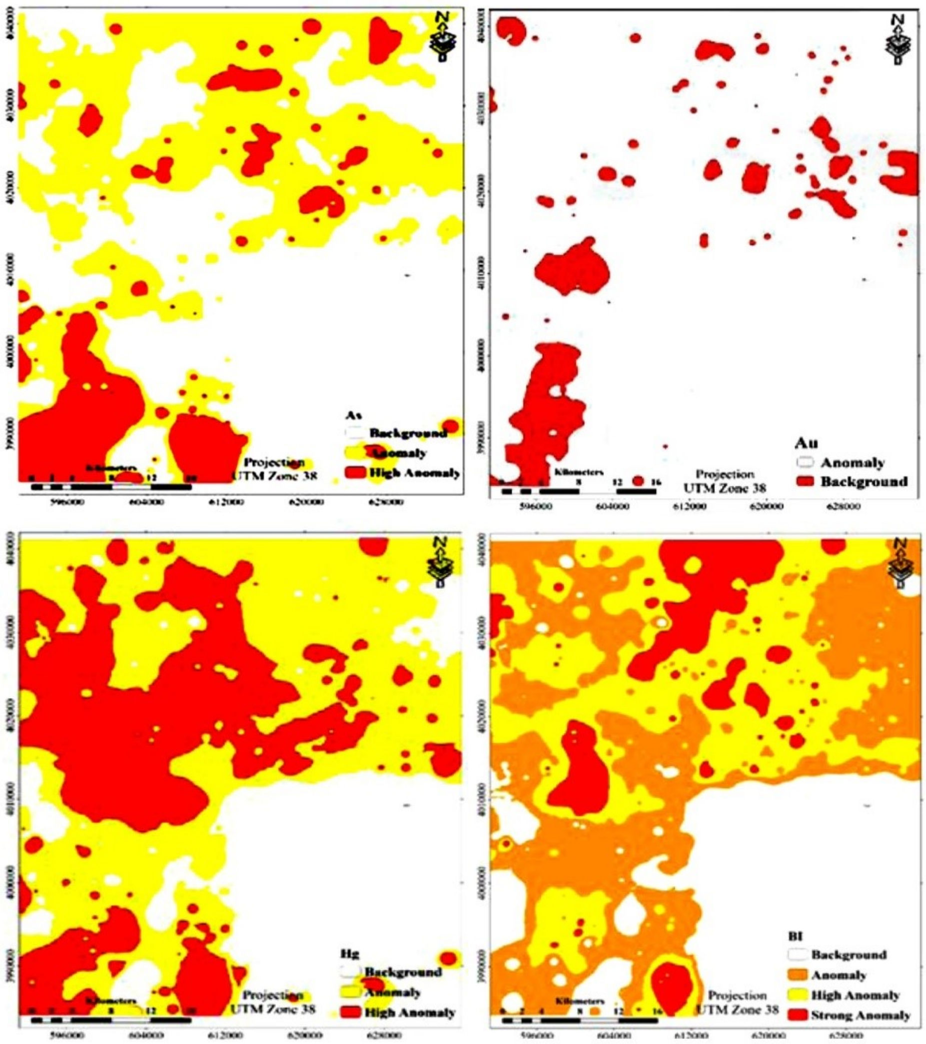

Fig 8. Anomaly separation map of gold, arsenic, bismuth and mercury using concentration-area method in Saqez sheet

Table 3 shows the various anomalies threshold limits of the elements based on concentration-number fractal method. Based on logarithmic graphs in the element of gold, four geochemical communities can be seen, while for arsenic, mercury, and bismuth we can see three geochemical communities. According to the maps drawn, severe anomaly of gold and arsenic is seen in the South and South West sheet, and smaller anomalies in the center. Severe anomaly of mercury and bismuth can be observed in the center and West of the sheet, and smaller anomalies can be seen in South and South West sheet.

Table 3. Threshold limits of gold, arsenic, bismuth and mercury using concentration-number in Saqez sheet

Element	Background limit	Aanomaly limit	High anomaly limit
Gold (ppb)	≤398.1	501.18	≥ 501.18
Arsenic (ppm)	≤12.58	50.11	≥ 50.12
Bismuth (ppm)	≥125.10	251.95	≥ 251.96
Mercury (ppm)	79.15	199.52	≥199.53

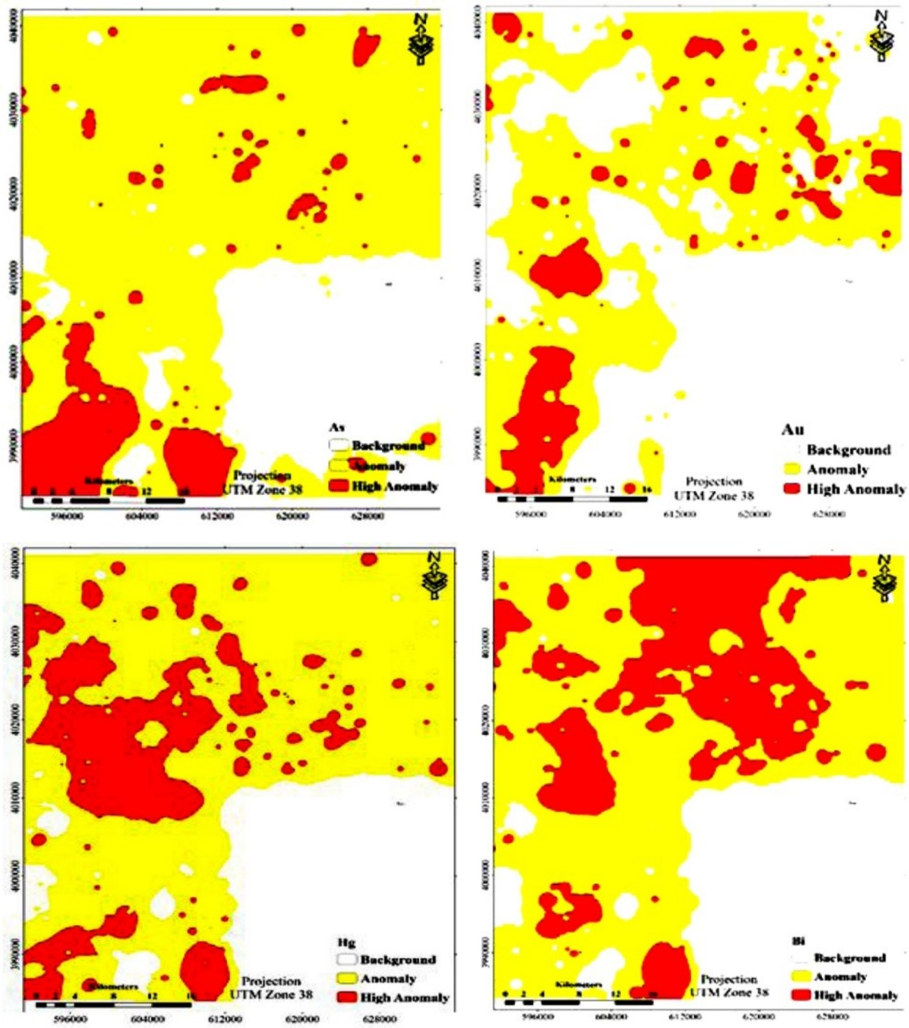

Fig 9. Anomaly separation map of gold, arsenic, bismuth and mercury using concentration-number method in Saqez

5. Conclusion

Comparison of fractal methods indicates that the resulted anomalies have partial overlap with each other. Concentration-area and concentration-number fractal methods are very important for the data resulted from stream sediments and can be used instead of other methods such as network estimation. As seen in Figures 7 and 9, anomalies obtained by concentration-number method overlap well with the anomalies obtained by Concentration-area method. This has caused anomalies of gold and its detectors such as arsenic, mercury and bismuth have the highest compliance with existing ores and indices including Qolqoleh, Kervian and Qabaghloujeh. Concentration-area and concentration-number fractal modeling results with zones having mineralization in Saqez 1:100,000 sheet, shows that the obtained anomaly has a very strong compliance with rock units having these areas including acidic volcanic, mafic and volcanic-sedimentary metamorphic rocks (acidic and basic metavolcanic and sericite schists) which are completely deformed. As can be seen in Figure 1, the anomalies associated with both methods show relative compliance with intrusive masses of Late Cretaceous which can be caused by the remobilization of metal elements and its re-enrichment around the mass.

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