Integration of Fractal modeling and Correspondence Analysis Reconnaissance for Geochemically High-Potential Promising Areas, NE Iran

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Highlights:

Bullet Points

- Correspondence analysis is one of the multivariate statistical techniques that applies to categorical rather than continuous data.
- Similarly to principal component analysis, Correspondence analysis provides a means of displaying or summarizing a set of data in 2D graphical form.
- Fractal geometry describes the "texture" of a surface. A "fractal" object has an intermediate dimensionality; the higher the fractal dimension, the finer and "rougher" the texture.
- Integrating the correspondence analysis and fractal method, fluvial sediment sampling have been considered to produce elemental distribution anomaly maps.

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Abstract

Most geochemical and geostatistical analysis in mining exploration requires removing regional trends in order to obtain local anomalies. In this paper, stream sediment samples, which collected from Khusf area (NE Iran), was studied based on Concentration-Area (C-A) fractal model as well as correspondence analysis methods to find high-potential areas elements. Correspondence analysis with 170 samples through 20 elements concentration values in each sample was performed. According to correspondence analysis, among one or several elements in the study area, local anomalies were separated which the highest concentration relates to the variables Pb, As, and Cd elements. After the correspondence analysis, the best variogram for the Khusf area was studied. Elemental concentration maps was then produced through estimating the values using kriging method. Therefore, using the fractal method, between three statistical sets of elements, it was concluded that the third set showed the anomaly for Pb, As, and Cd elements with local anomaly values respectively determined as 55, 7.2, and 0.88 ppm. Although Cd element is not genetically related to same source of Pb and As, utilizing integrated approach, Cd anomalies has also been detected in the area as a promising element zone. Finally, it is suggested that this region has the possibility of Basic Metals occurrence and suggests further geophysical operations on a local identification scale.

Keywords

Correspondence Analysis, Concentration-Area (C-A) Fractal Method, Variogram, Geochemical Anomaly Separation, Basic Metals

1. Introduction

Anomaly separation from the background is one of the most significant and substantial stages in geochemical explorations (Hassani Pak & Sharafaddin, 2003; Rastegari Mehr et al., 2020). Most geochemical, statistical, and geostatistical works in exploratory affairs require regional anomaly (trend) removal. From a geological viewpoint, the anomaly is a variation from what is expected, i.e., the threshold limit is defined concerning the expected value, which is generally referred to as the background trend (Ghorbani et al., 2022; 2023; Jozani Kohan, 2015; Li et al., 2003; Mami Khalifani et al., 2018; Mohammadi Asl et al., 2020).

The fundamental prerequisite of geochemical and geostatistical computations includes suitable samples to provide the initial raw data as concentrations for the elements. In general, economically worthy indices, specifically metal mines, have become particularly significant considering the current demand and novel technologies (Cheng et al., 1996; Shahbpour, 2010).

Different methods are used to remove regional anomalies to determine local high-potential zone. Such methods include fractal geometry, U spatial statistic, surface trend technique, Correspondence analysis, factorial analysis, and so on (Abdi & Williams, 2010; Darabi Golestan et al., 2019; Greenacre, 2007; Hassani Pak & Sharafaddin, 2003).

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Geochemical sampling involves collecting various earth materials such as rocks, soils, sediments, and water. Different geochemical sampling methods have conventionally been used to study different aspects of mineral exploration, geological analysis and environmental studies. Variations in chemical compositions of certain earth materials are descriptors of the environment in which those materials occur or are derived from them. Geochemical explorations have remarkably aided the attainment of this objective. Geochemical research on the samples taken from the field aimed at determining threshold limit and the minimum anomaly is highly recommended. In order to provide required data set, samples from soil was collected and sub samples with the size accumulated below 80 mesh sieve was selected for geochemical analysis such as atomic absorption analysis. Then, determining the threshold limit is an essential and primary factor for subsequent actions. Analysis of fluvial sediment samples is among the most critical stages for assurance about any region's presence or absence of basic metal anomalies (Abedi-Orang et al., 2020; Cheng et al., 1996; Darabi Golestan et al., 2019; Ghorbani et al., 2020; Li et al., 2003; Losa et al., 2016).

Recently, the weighted drainage catchment basin (WDCB) modeling of stream sediment geochemical landscapes used as an approach whereby the relative importance of all stream sediment samples and geochemical anomaly classes (such as strongly anomalous, moderately anomalous and background) in every drainage catchment basin (DCB) were considered in assigning a weight to each of them for prospecting of mineral deposits (Ghaeminejad et al., 2020; Ghasemzadeh et al., 2019; Movahhed & Yousefi, 2019; Yousefi & Carranza, 2015; Yousefi et al., 2013).

Fractal geometry methods are mainly used to analyze complex shapes of geological structures, especially in structural geology and engineering branches, especially in economic geology, mining, geophysical analysis as well as geochemical anomaly separation to highlight mineralogical concentrations (Darabi Golestan et al., 2013; Jagodzinski et al., 2023). Also, fractal methods as a relatively novel methods, are among the essential spatial analysis techniques. Producing anomaly maps needs to consider spatial coordinate of the samples in addition to the concentration of an element in each sample. The fractals describe nature as nature rules, which is regarded as a great advantage. Nature geometry fractal is a solution to the numerous applications in various sciences (Cheng, 1999; Losa et al., 2016; Mandelbrot, 1983). Among these methods, grade-area, grade-number, and power-area spectrum methods are very useful in earth sciences. Mandelbrot (1983; 1985) and Agterberg (1993) proposed a value-size method for determining threshold values as geochemical properties background trend. Afzal et al. (2011) drew a logarithmic diagram of Concentration-Volume wherever the slope of the curve has changed drastically that indicates a sharp change in grade as a function of changing geological and mineralization conditions (Afzal et al., 2011; 2019; 2022; 2023; Kianersi et al., 2021; Kianoush et al., 2022; Mahdizadeh et al., 2022; Mirzaei et al., 2022; Soltani et al., 2014; Zissimos et al., 2021). Several fractal methods have been developed and applied in geochemical explorations, such as Concentration-Volume (C-V) by Soltani et al. (2014). Recently, compressional velocity-volume (Vp-V) and some pressure-volume (P-V) fractal models have been presented by Kianoush et al. (2022).

The fractal method has remarkable accuracy in anomaly separation from the background comparing to conventional methods. The selection of a method for specifying geochemical anomalies depends on the distribution pattern of the data and elemental concentration in rocks and sediments (Abedi-Orang et al., 2020; Kianoush et al., 2023; Li et al., 2003).

The best advantage of Correspondence analysis is the flexibility in terms of data requirements, which allows for geoscience knowledge incorporation. Correspondence analysis is a versatile and easily implemented analytical method that can do much to assist researchers in detecting and explaining relationships among complex geochemical anomalies; so fractal geometry geochemical method successfully separates local geochemical concentration anomalies from the background. Although models help identify the geochemical anomalies within a region, including a simple geological background; it has limitations within a region linked with a complex geological setting, where different geochemical fields characterize each sub-area. Thus, it could not identify the weak anomalies properly.

In this study, Khusf stream sediment was studied based on fractal geometry and correspondence analysis methods for the first time in this region. The respective methods and their simultaneous utilization are intended to integrate the results acquired and enhance work accuracy. This paper conducted a chemical analysis of fluvial sediments to find high-potential areas of Pb, Cd, and As elements in the Khusf area of South Iran's Khorasan province.

In this article, an analysis of the characteristics of stream sediment geochemistry data for the region indicated that concentration values of deposit pathfinder elements of Pb, As and Cd involve multiple chemical element populations and complex spatial dispersion patterns. The application and quantitative comparison of the two frequency space-based methods, Correspondence analysis and C-A fractal models, demonstrated that the C-A fractal approach yields a better model and can decompose geochemical anomalies, more effectively.

In general, in fluvial geochemistry studies, since the elements are separated from their source, the mobility of each element is different from the other. Considering that the main goal of these studies was the exploration of elements such as gold, arsenic, and lead, the presence of a cadmium mineralization group next to lead and arsenic with a concentration of 1.68 to 1.48 ppm by combining the methods used indicates the promising element zone of cadmium (Cd). Although, each of the Correspondence Analyzes and Fractal Modeling methods has been used separately in previous studies, as mentioned above, but the integration of these two methods provide a novel approach in determining the promising zone of the Cd element in the studied area.

2. Geological Setting of Study area

The study area is located along longitudes from 58° 45" to 59° and latitude from 32° 45" to 33°, in 1:50,000 sheet of Khusf,1:100,000 geological map of Khusf, 35 km to the west of Birjand city located in South Khorasan Province, NE Iran (Fig. 1). The study area is located on the northern part of Central Lut Desert.

In this reconnaissance, this area is located in highlands and mountains in the northern and northeastern parts of Iran. In other places, the hills and alluvial plains enclosed between them are the lowlands and heights of the region; which among them, volcanic rocks are scattered and base metal anomalies usually occurs at coincide with geochemical halos. There are widespread exposures of Late Cretaceous-Early Tertiary sedimentary rocks and Cenozoic volcanism conclude elevated areas and mountain ranges are arranged in the northern and northeastern parts. In distinction, in the other parts of area, the topography is dominated by abundant irregular hills and intervening alluvial plains with scattered, higher, and isolated volcanic bodies. The oldest rock units in the area include upper Palaeozoic which are restricted to small fractured and faulted fragments of the central Iranian Palaeozoic platform and are exposed as an anti-form in the northwest of the map. The lithology units of the study area are Flysch-type sediments, marl, and limestone. During the mid-Eocene, non-volcanic deposits, including agglomerate, ignimbrite, marl, and tuff, have been found in the northwest and southwest corner of the sheet. Eocene-Oligocene volcanic rocks, including Andesite, Tuff, and Dacitic-andesite, were seen in the studied area. Eocene-Oligocene dacite, silicified volcanic rocks, and Oligo-Miocene rhyolite sand dacites have been formed in sheets. A geochemical drainage survey was carried out to identify a promising area in the Khusf 1:100000 sheet, and 652 geochemical samples were taken. Fig. 2 shows the stream sediment samples' location in the study area. The minus 80-mesh fraction of the stream sediments was analyzed for 20 elements, including Au, W, Mo, Zn, Pb, Ag, Cr, Ni, Bi, Sc, Cu, As, Sb, Cd, Co, Sn, Ba, V, Sr and Hg, and three oxides, MnO, TiO_2 and Fe_2O_3 (Darabi-Golestan & Hezarkhani, 2018; Keykhay-Hoseinpoor & Aryafar, 2014).

3. Methodology

Currently the global uncertainty and sensitivity analysis is widely performed in various disciplines involving social science, engineering science, geoscience, chemistry, physics, etc. It has been stated as a formal tool for statistical evaluation of models and often contributes to models' quality and application. Specifically, the global sensitivity analysis is beneficial for gaining insight into how input parameters can be ranked according to their importance in establishing the uncertainty of model response (Ghaeminejad et al., 2020; Yousefi & Carranza, 2015; Zhu et al., 2018). Criteria for selecting data acquisition devices and parameters, and for selecting characterization parameters, can be based on scale. The scale-of-interaction of interest, typically related to performance parameters or process variables, needs to be included in the scale-of-interaction in data acquisition and preserved in the analysis or simulation in order to make realistic functional correlations (Fig. 3). In Fig. 3, *the scales are indicated as: a) interactions determining performance; b) interactions from the process creating the surface; c) data acquisition, the finest scale is the resolution; and d) preserved in the analysis.* The only exception is when there is geometric self-similarity with respect to scale so that the analysis can be extrapolated to scales not included in the data (Afzal et al., 2023; Brown et al., 1998; Ghasemzadeh et al., 2019; Kirkby, 1983; Movahhed & Yousefi, 2019).

The patchwork, or virtual tiling method, for analyzing areas (Brown et al., 1993), measures the topographic data using discrete triangular patches, or tiles. This method approximates the areas of surfaces by repeated measurements at different scales. The different scales are represented by the areas of the triangular patches. This method can also provide the basis for scale-sensitive simulations. Fractal analysis can be performed in a scale sensitive manner, to improve the description of the topography of engineering surfaces. This scale sensitive fractal analysis can be used as the basis for simulating interactions with engineering surfaces (Afzal et al., 2022; Brown et al., 1998; Yousefi et al., 2013).

In the present paper, fractal geometry and Correspondence analysis methods were applied. The studies were performed on data from 170 fluvial sediment samples for 20 elements. The respective methods and their simultaneous utilization are intended to integrate the results acquired from the respective methods and enhance work accuracy. Regular gridding obtained through Kriging interpolation of the data values, as an appropriate estimation approach, was used to map concentration data required to perform fractal methods. Considering the grid of data over the studied region, a log-log fractal diagram is plotted using concentration–values, the threshold limit value is determined, and anomaly zones are specified. The intersection point of two terminal lines with more distinct slopes in the log-log fractal diagram is assumed as the threshold limit of anomaly sets.

3.1. Correspondence Analysis

The correspondence analysis technique was used to simultaneously investigate the samples and variables to achieve an overview of the sample and the existing anomalies (Mandelbrot, 1983; Mellinger, 1984; 1987; Valenchon, 1982). The data matrix is a 175*20 matrix in which the summation of values in every column forms a vector represented by [r]. Moreover, the summation of each column of the respective matrix forms a vector denoted by [c]. The respective matrices are computed in MATLAB software. Therefore, any member of the respective vectors can be defined via Eqs. (1) and (2):

$$r_i = x_{i1} + x_{i2} + \ldots + x_{im} \tag{1}$$

$$c_j = x_{1j} + x_{2j} + \ldots + x_{nj} \tag{2}$$

Now, two diagonal matrices [R] with n * n dimension and [C] with m*m dimension are defined as Eqs. (3) and (4):

$$\left[R\right] = diag(r_1, r_2, \ldots, r_n) \tag{3}$$

$$\left[C\right] = diag(c_1, c_2, \ldots, c_m) \tag{4}$$

Therefore, [R] and [C] are diagonal matrices in which the elements on the principal diagonal are the r_is and c_is. Now, matrix [W] is defined as Eq. (5):

$$\left[W\right] = \left[R\right]^{-(\frac{1}{2})} \left[X\right]\left[C\right]^{-(\frac{1}{2})} \tag{5}$$

In the equation above, the power (-1/2) means firstly the whole matrix elements are reached to the power of ½ and then transpose of the matrix is evaluated. And ultimately, matrix [H] is evaluated as Eq. (6):

$$\left[H\right] = \left[W\right]^T \left[W\right] \tag{6}$$

Once matrix [H] is evaluated, its eigenvalues and eigenvectors can be determined too. [H] is a 20*20 background whose values are chosen from zero to one. P of eigenvalue is achieved where P is permanently area than m (P < m) (Eq. (7)):

$$0 < \lambda_p \leq \ldots \leq \lambda_2 \leq \lambda_1 < \lambda \tag{7}$$

The eigenvectors corresponding to each eigenvalue [a_j] are also calculated. Then, the following two matrices can be formed based on eigenvalues and eigenvectors according to Eqs. (8) and (9):

$$[\Lambda]_{(p\times p)} = diag(\lambda_1, \lambda_2, \ldots, \lambda_p) \tag{8}$$

$$[A]_{(m\times p)} = \left[[a_1][a_2]\ldots[a_p]\right] \tag{9}$$

Where [Λ] is a diagonal matrix where the elements on the principal diagonal are the same as the above mentioned eigenvalues, and [A] is a matrix in which every column constitutes one of the eigenvectors, and then two matrices can be calculated as Eqs. (10) and (11):

$$[U]=[C]^{-\frac{1}{2}}[A][\Lambda]^{\frac{1}{2}} \tag{10}$$

$$[V]=[R]^{-\frac{1}{2}}[W][A] \tag{11}$$

Matrix [U] is an m*p matrix and expresses the relationships among the variables, and matrix [V] is an n*p matrix that expresses the relationship among the samples. The ultimate matrix is generated based on correspondence analysis and via a combination of the two matrices mentioned above. The resulting matrix (Eq. (12)) is an m+n row matrix, and p is a columnar matrix (Ghorbani, Gholizadeh, et al., 2022; Hassani et al., 2009; Reis et al., 2004):

$$[F]=\begin{bmatrix}[V]\\ [U]\end{bmatrix} \tag{12}$$

In order to analyze the binary correspondence factors of the matrix columns, [F], i.e., the factors, is plotted in a distribution diagram. Therefore, [p*(p-1)]/2 diagrams are achieved.

3.2. Concentration-area fractal modeling

To estimate anomaly, the acquired samples shall be formed into regular gridding. For this purpose, proper variograms shall be plotted on the region's data. Estimation is made using the Kriging technique and a 1000 m*1000 m grid. The variogram γ (h) is used to express the spatial dependence quantity of samples (Eq. (13)) :

$$\gamma(h)=\frac{1}{2m(h)}\sum_{i=1}^{m(h)}(z(x_i)-z(x_i+h))^2 \tag{13}$$

where m(h) is the number of sample pairs used in the computations for a specific distance of h, z denotes the grade value of the measured variable, and m is the number of samples taken in the sampling medium (Sumfleth & Duttmann, 2008).

The first stage of deploying the fractal geometry method is to generate a variogram for the study region. A variogram is defined based on a set of equations and, in a more general sense, represents a measurement of the spatial variations for geostatistical studies (Barak et al., 2018; Deutsch & Journel, 1998). A great deal of information is gained from variograms, and there are numerous applications for performing statistical works, but many things shall considered for plotting variograms. The selection of lag size is exceptionally significant in empirical variogram analysis. If sampling is done in a regular grid and (or) a medium with a minor disorder, lag size shall equal the distance of the sampling points. If the lag size is smaller than the distance of the sampling grid, the variogram value in the selected distance will underestimate the actual value. If the lag size is larger than the distance of sampling points, the correlation structure will not be reflected in the variogram, the domain will not be observed, and even a pure nugget effect might be caused. If the lag size is significantly smaller than the sampling distance, the number of pair points included in variogram value estimation will be limited, and therefore the estimated value will be statistically insignificant (Isaaks & Srivastava, 1989; Kianoush et al., 2022; Mirzaei et al., 2022).

4. Results

The fractal method's application is in identifying local anomalous sets from background. Different types of fractal analysis are Grade – area, Grade – perimeter, Grade – distance, and power spectrum techniques. Here, a log-log plot of grade values is used versus area. The respective diagrams represent the relative–exponential relation between A(ρ) areas with grade values of the elements equal or greater than grade values of ρ (Eq. (14)):

$$A(\rho)\propto C\rho^{-\alpha} \tag{14}$$

where “C” is a constant of fractal, and α is a power that might represent several values for different domains of geochemical concentration in the Grade – Area plot. The corresponding discontinuous values between the lines are used as cutoff grade for separating geochemical values into different subsets reflecting various influencing factors such as lithological separation and geochemical processes. (Like mineralization events, grade of surface geochemical elements, and surface weathering).

The Fig. 4 illustrates instances of the respective diagrams in which the separation of one or several variables is a reason for the presence of abnormal values. Moreover, separating one or several samples in a specific direction indicates that the sample is anomalous to the respective element. Furthermore, these samples suggest a higher likelihood of anomaly of the respective variable in the region, taking into account their extreme skewness toward the variable and less skewness toward the surrounding samples. Thus, this zone has probable anomalies to Pb, As, and Cd variables in certain areas, and samples no. 144, 135, 111, and 113, and to some extent, 147 and 175 have the largest Pb, As, and Cd concentrations (Fig. 3).

Fig. 5.a illustrates the resulting variogram for the Pb element plotted along the maximum continuity. The results obtained from this variogram (range, nugget effect, sill, and model type) are used for Kriging estimation and a grid designed for the region. The Pb, As, and Cd estimation results are plotted in Fig. 5.a to Fig. 5.d, where several zones with higher concentrations are seen for each element. For Pb element the radius effect is 2500m, nugget effect is 0.2, sill is 1 with spherical fitting method. Almost similar behavior of variogram maps for Pb, As, and Cd, reveals the similar spatial distribution within the area, which may suggest their distribution correlation.

The estimation results for the three elements of As, Cd, and Pb are categorized into 20 classes. Their log-log diagrams are plotted by applying particular statistical computations (Fig. 6 to Fig. 8). The discontinuity points indicate changes of values in the data sets. Accordingly, the threshold limit of the data sets can be determined. As implied earlier, the intersection point of the two last lines with more distinct slopes is assumed as the threshold limit for the separation of anomalous sets. The third set in fractal shapes represents the zones for the resumption of work and the excellent likelihood of the presence of an anomaly. The corresponding value for Pb is 55 ppm, above which the values can be further investigated and are more anomalous than the other samples. Fractal diagrams of other elements are also plotted. The promising zones are specified for the elements As and Cd, correlate well with the Pb element, and require further studies (Fig. 7 and Fig. 8).

Integration of Correspondence Analyzes and Fractal Modeling methods defining the promising zone of the Cd element in the studied area. Local anomalies obtained from applying correspondence analysis and log-log fractal study is mainly located in the Eastern part of area coincide with Phyllite-Slate, Dacite-Andesite, and Pyroclastic rock units.

5. Discussion

It has been empirically proven that anomalous concentration of metals in fluvial sediments is detected in fine-grained components of the respective sediments. The results from numerous experiments indicate that stream sediments of 80 mm mesh could prove highly beneficial in regional exploration (1: 250,000 to 1:100,000). The results of these samples may be helpful in the analysis of geochemical provinces and recognition of regional geochemical patterns and also the areas where the likelihood of discovery of mineral masses is high (Cheng et al., 1996; Geranian & Tabatabaei, 2020; Hassani et al., 2009; Nazarpour et al., 2014).

In such cases where the goal is to discover the secondary geochemical halos, it is necessary to benefit from statistical techniques. It would maximize the difference between the anomalous values and regional trends and hence, would help in the more accurate identification of anomalies through the intensification of their presence. A standard method for estimation and performing statistical works is to primarily transform the data (such as normalization, Box-Cox transform, and log-normal transform) and to analyze the transformed data. Furthermore, the estimation results are ultimately restored to the initial state (Goovaerts, 2009).

The selection of a method for specifying geochemical anomalies depends on the distribution pattern of the data. On the other hand, the use of the respective method is efficient due to the spatial distribution of elemental concentration in rocks and sediments and mainly tends to demonstrate fractal trends. Different geostatistical methods are used to separate anomalies and determine a high-potential zone. Regular gridding was used to perform fractal methods, and an appropriate estimation was made. It has been plotted using grade–area method, the threshold limit value is determined, and anomaly zones are specified. The breaking point of two terminal lines with more distinct slopes in the log-log fractal diagram is assumed as the threshold limit of anomaly sets.

The noisy data are initially replaced to interpret the data. Then, Correspondence analysis is performed on the data and the Pb, Cd, As, and Bi elements among the whole elements correlated with each other to some extent. Since the goal was to find promising zones in Khusf Region for base metals at the beginning of exploration operations, only the results of the Pb, Cd, and As elements are discussed here.

Variography has shown that each sample influences its neighboring samples up to a radius of 2,500 meters, and the continuity of anomalies is mainly in the northeast-southwest direction. With the help of variogram characteristics on the normalized data, each network's estimation was done with a dimension of 1000*1000 meters according to the samples up to 2500 meters radius. Then, the data were returned to their actual range.

Since the distance of sampling points is considerable from one another and these operations have been carried out for preliminary assessments and at a scale larger than local, there is a need for further investigations, particularly in promising zones demonstrated for Pb, As, and Cd (Fig. 9.a to Fig. 9.c). As shown in Fig. 9.a, the Pb grade concentration in the northern part of the studied area is highest, especially in NE, with a range of 85-90 ppm. Furthermore, in Fig. 9.b, and Fig. 9.c, Cd and As elements concentration is highest in the eastern part of the Khusf region with 1.48-1.68 and 9.2-11.2 ppm, respectively. Although Cd element is not syngeneic of Pb and As, Cd anomalies from different source compare to Pb and As has been revealed through applying integrated approach analysis. Cd anomalies has been located on Phylite-slate and Dacite units in central eastern part of the study area, as in the North Eastern part, Cd anomalies is located on Ignimbrite and Marl-conglomerate outcrops (Fig. 10).

6. Conclusion

- Integration of Correspondence analysis with Log-Log fractal study has introduced as effective tools in separating element anomalies related to different source.
- Correspondence analysis indicated anomalies of the Pb, As, and Cd elements. The fractal method also determined three statistical sets where the third set showed anomaly for all three elements to some extent. The approximate values of anomalies cut-off were evaluated as 55 ppm, 7.2 ppm, and 0.88 ppm, respectively, for Pb, As, and Cd.
- Generally, the northeastern (NE) part of the Khusf region has the highest potential for Pb, As and Cd elements. Almost similar behavior of variogram maps for Pb, As, and Cd, reveals the similar spatial distribution within the area, which may suggest their distribution is correlated.
- In the NE and southeastern (SE) parts of the Khusf region, extra sampling at the local scale helps to highlight the anomalies. Also, geophysical surveys might prove enormously effective.
- Local anomalies obtained from applying correspondence analysis and Log-Log fractal study is mainly located in the Eastern part of area coincide with Phylite-Slate, Dacite-Andesite, and Pyroclastic rock units.
- The presence of a cadmium mineralization group next to lead and arsenic mineralization with a concentration of 1.68 to 1.48 ppm by combining the methods used indicates the promising element zone of cadmium (Cd).

As a suggestion, the integration with other weighted evidence layers, such as fault density and proximity to argillic alteration, could yield a more precise targeting model that may display significant spatial correlations with various geological features favorable for exploration in the studied area (i.e., silicified veins, porphyry dikes, and intrusive rocks). Thus, more reliable targets will be identified for follow-up exploration.

Nomenclatures

[A]: matrix in which every column constitutes one of the eigenvectors
[c]: Summation Vector of each Column of the Respective Matrix
[R] and **[C]**: Diagonal Matrices
[r]: Summation Vector of Values in every Column

[Λ]: Diagonal Matrix
A(ρ): Areas with Grade Values
C: Constant of Fractal
h: Specific Distance
m(h): Number of Sample Pairs
m: Number of Samples Taken in the Sampling Medium
P: Eigenvalue
z: Purity value of the measured variable
α: Power of Fractal
γ (h): Semi Variogram
ρ: Grade Values

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Figure Captions

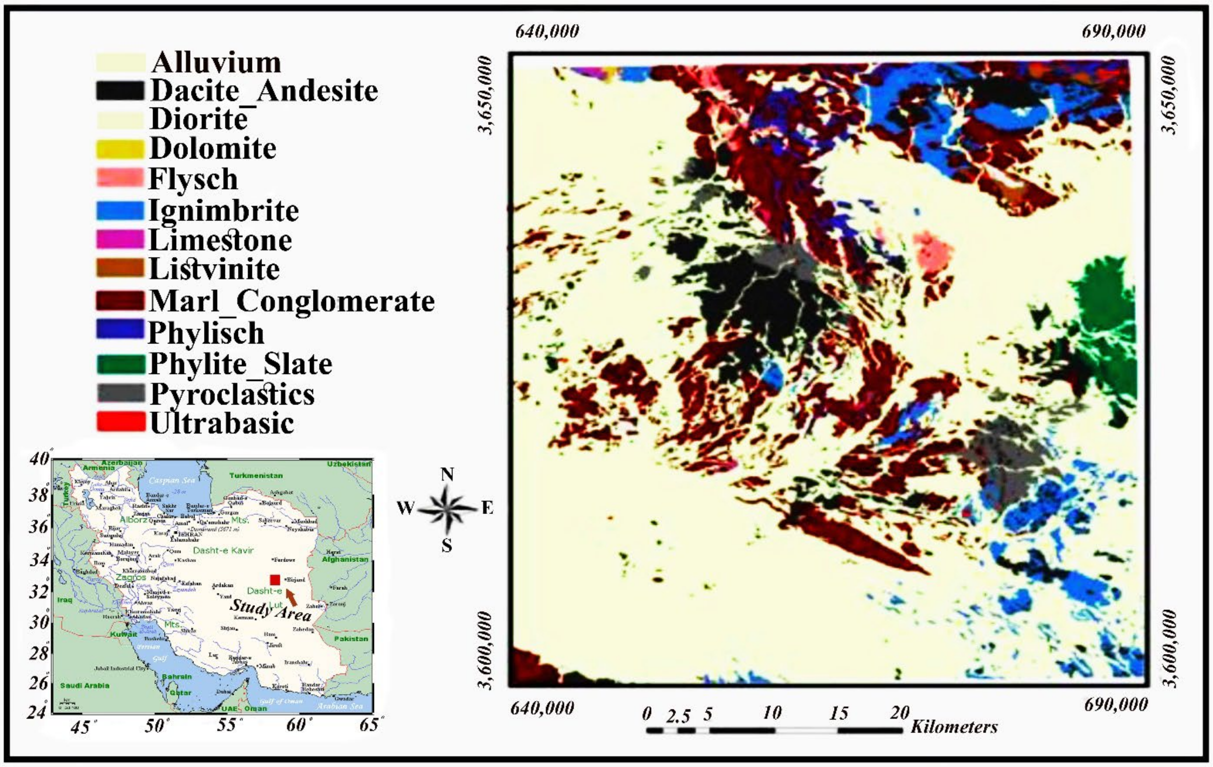

Fig. 1. Location of 1:100,000 sheet of Khusf and associated 1:50,000 sheets (Geological Survey of Iran).

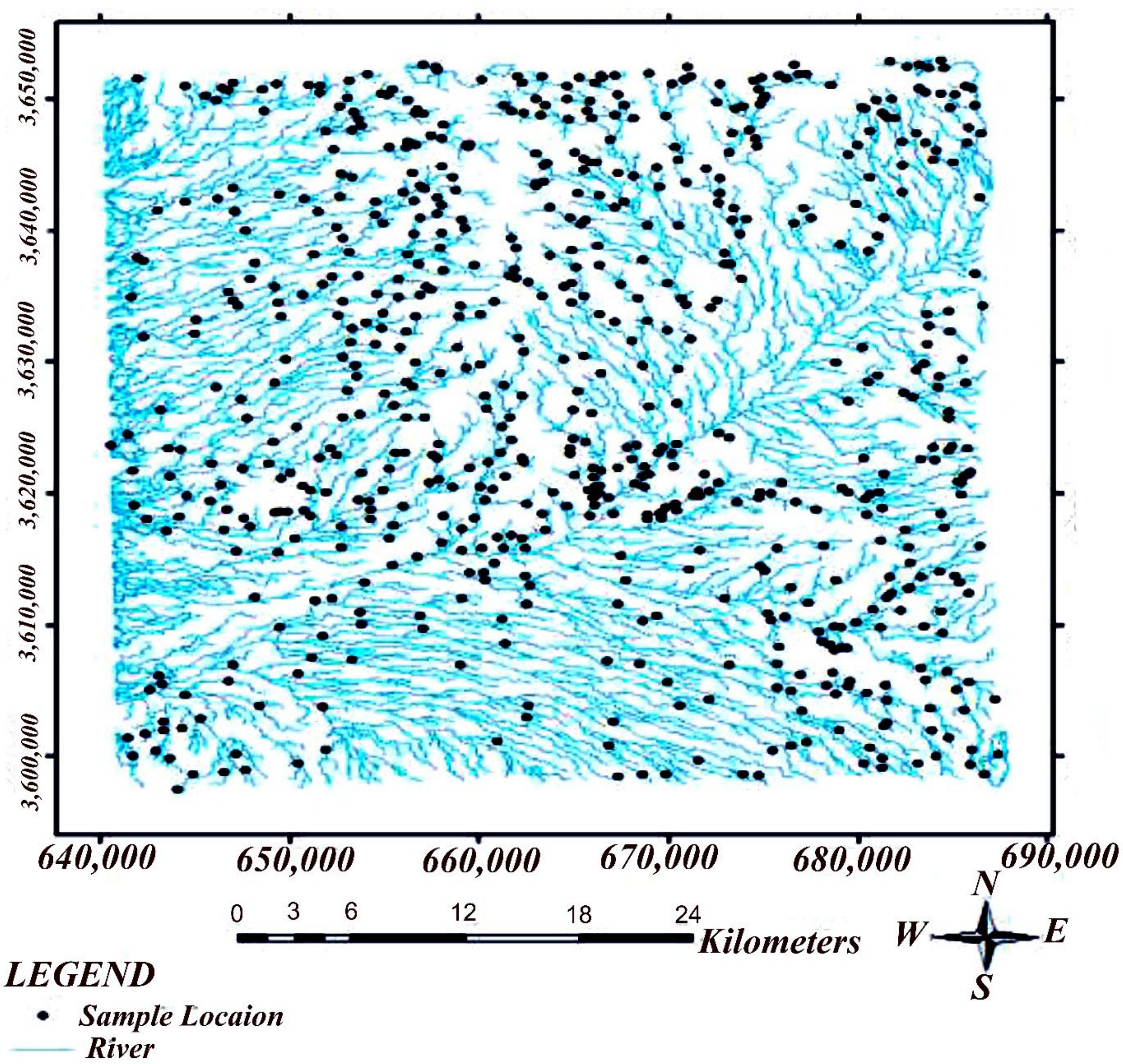

Fig. 2. Stream sediment samples' location in Khusf 1:100000 sheets (Keykhay-Hoseinpoor & Aryafar, 2014).

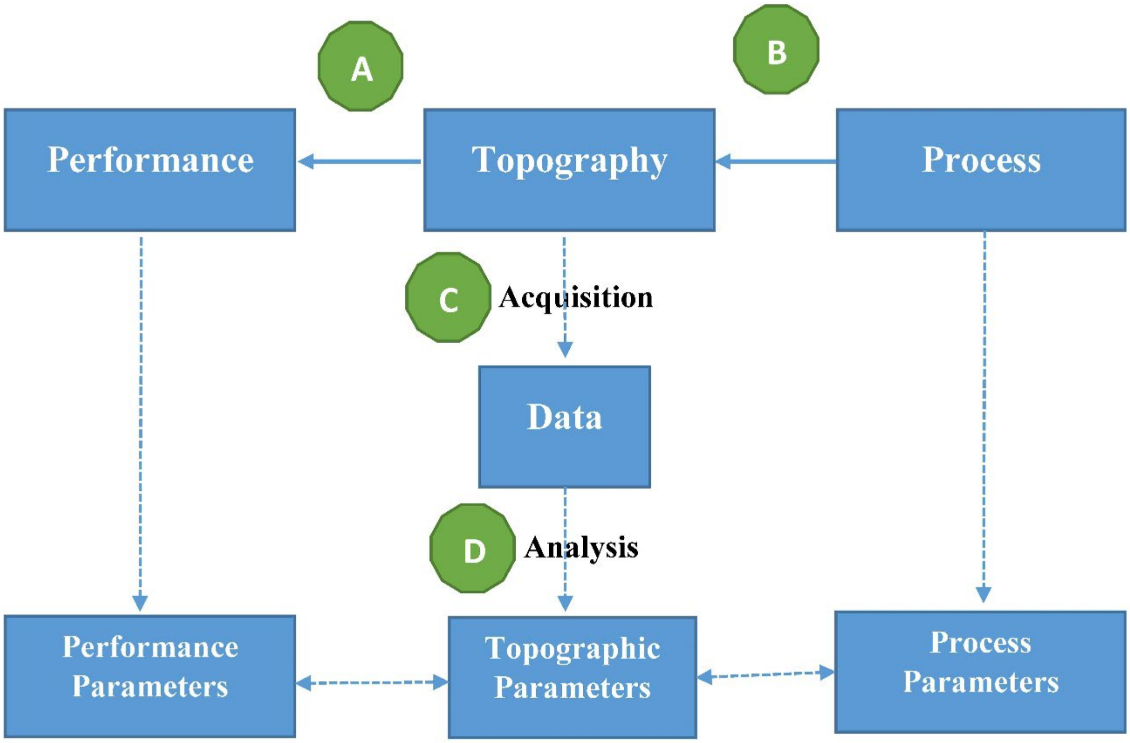

Fig. 3. Scale based flow chart for finding functional correlations. The double dotted arrows represent the functional correlations.

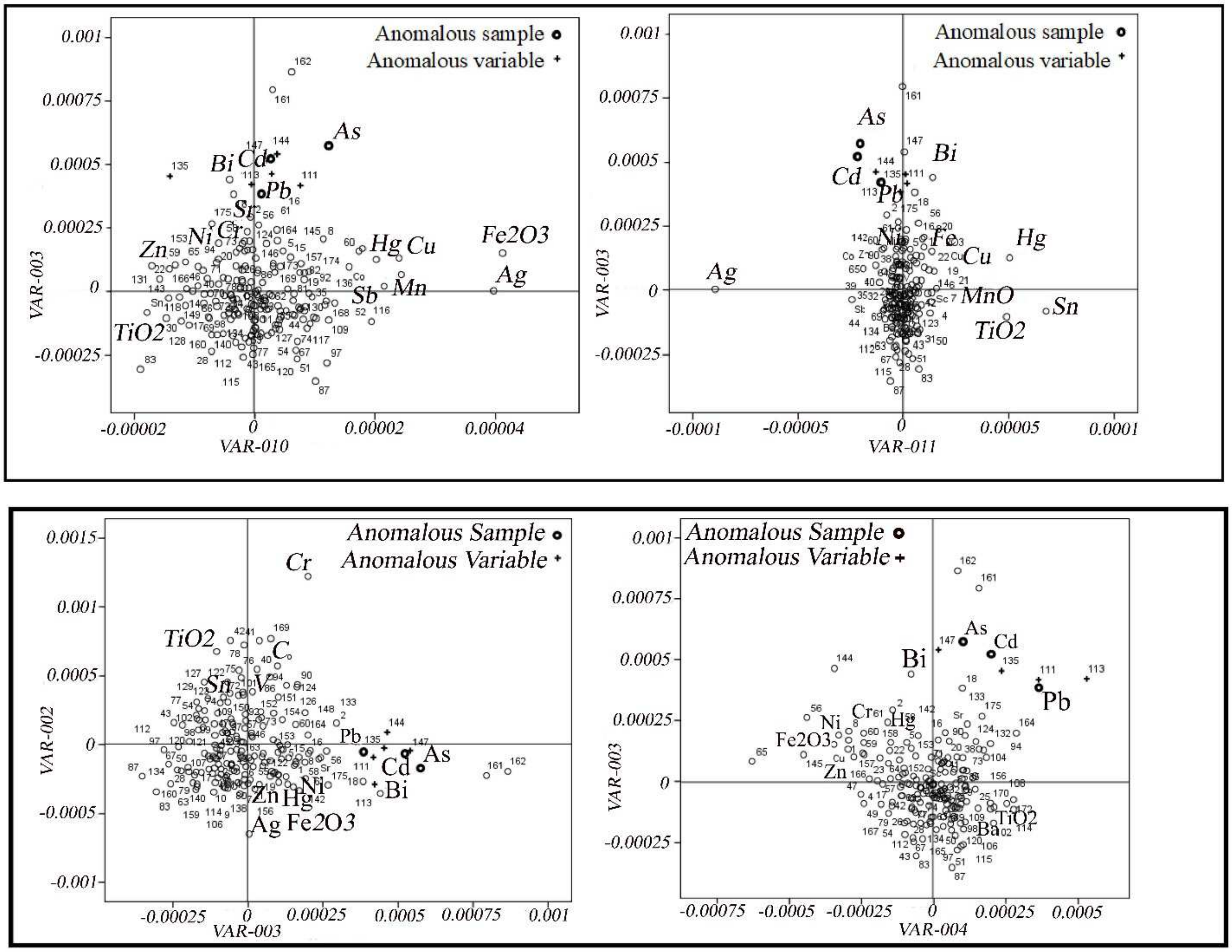

Fig. 4. Distribution diagram of variables and samples in factorial coordinate system.

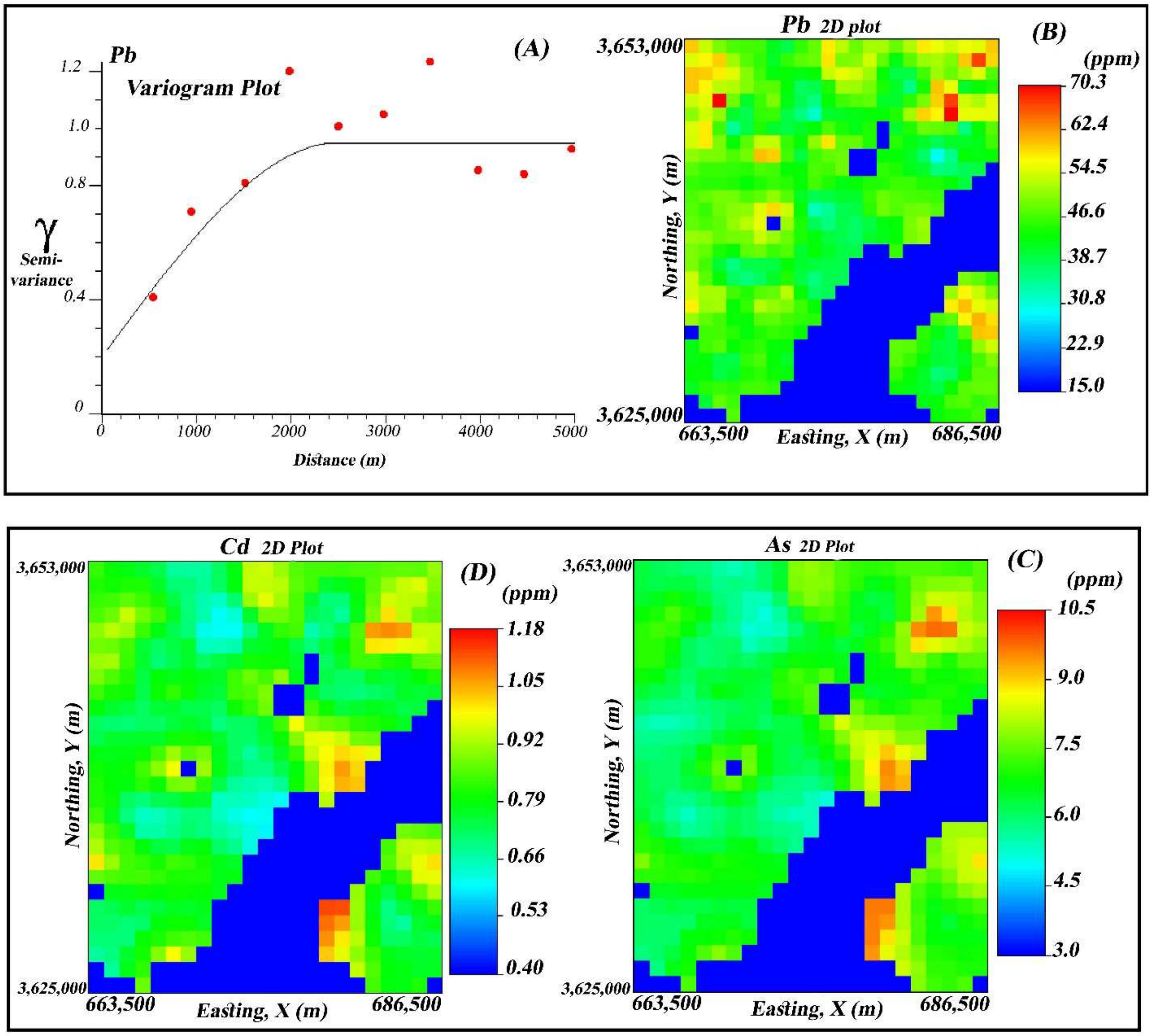

Fig. 5. The variogram with maximum continuity for a) Pb element, b) estimation results for the Pb elements, c) As, and d) Cd.

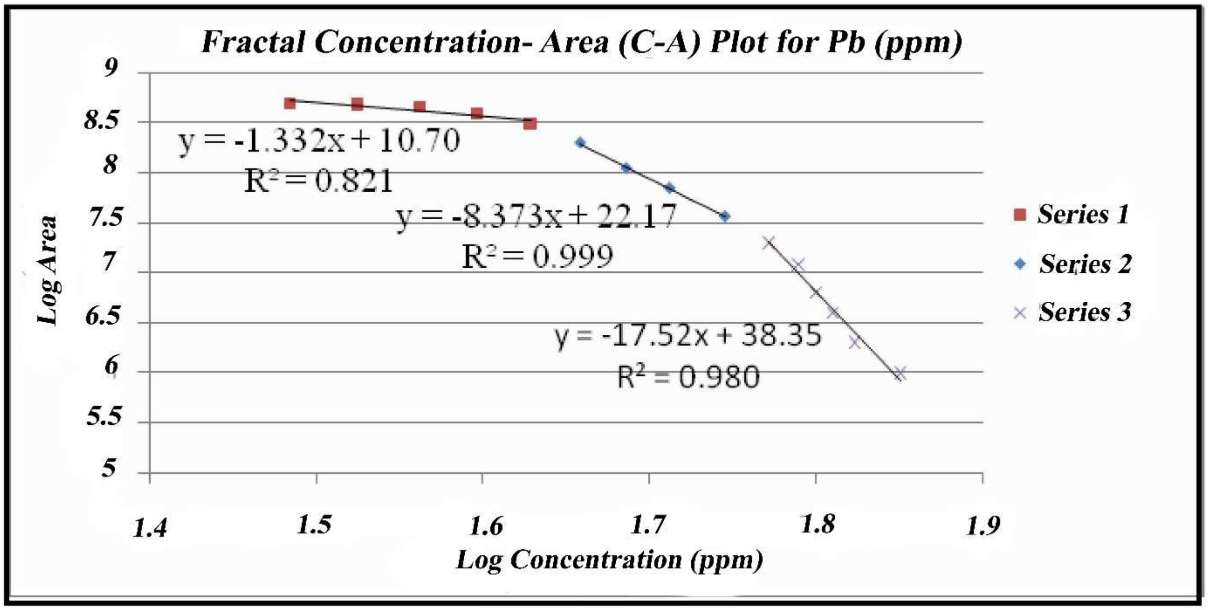

Fig. 6. Fractal Concentration – Area plot for Pb in ppm (minimum anomaly value equal to 55ppm).

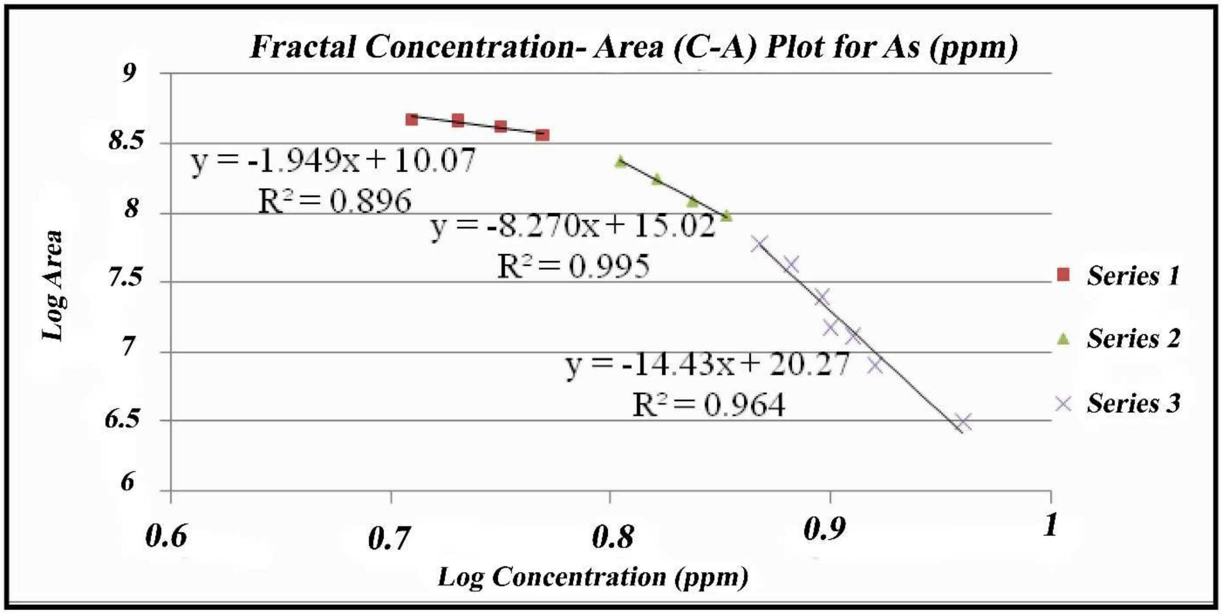

Fig. 7. Fractal Concentration – Area plot for As in ppm (minimum anomaly value equal to 7.2ppm).

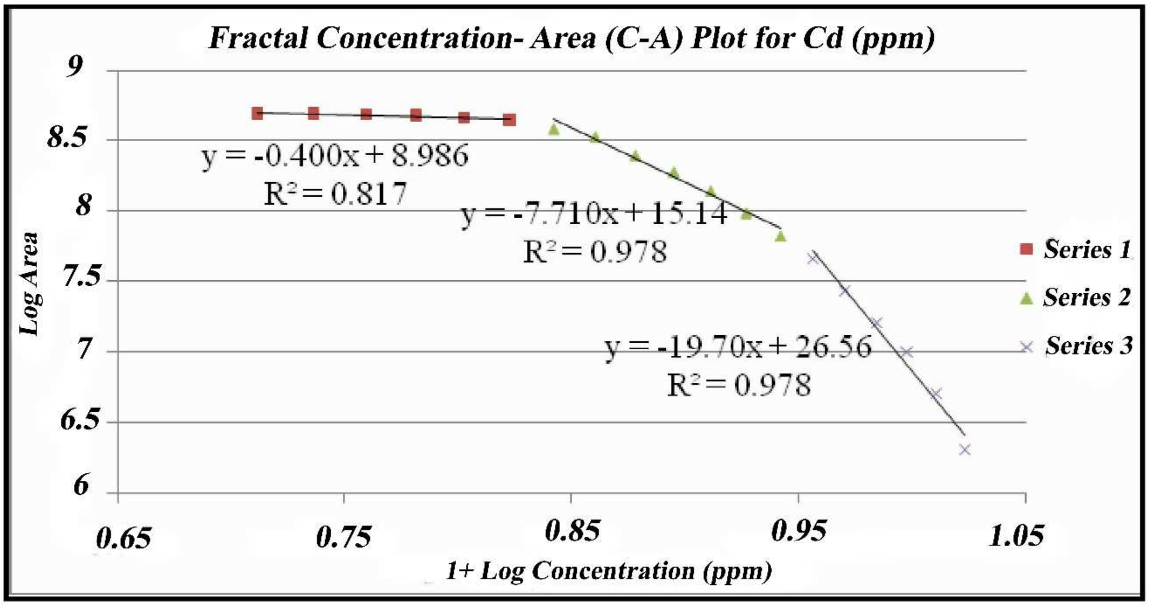

Fig. 8. Fractal Concentration – Area plot for Cd in ppm (minimum anomaly value equal to 0.88ppm).

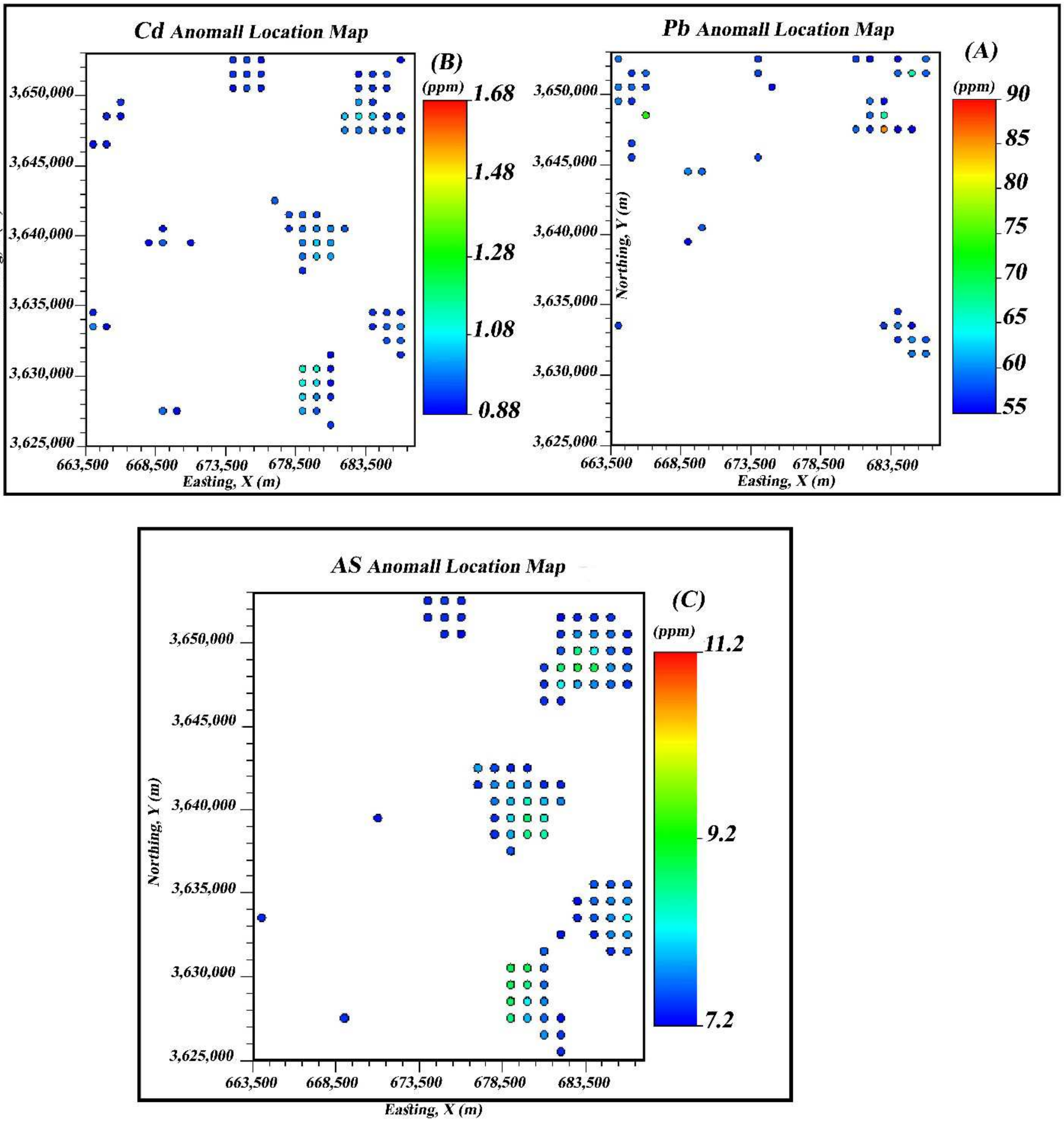

Fig. 9. Anomalous zones shown by fractal geometry method for the a) Pb elements, b) Cd, and c) As.

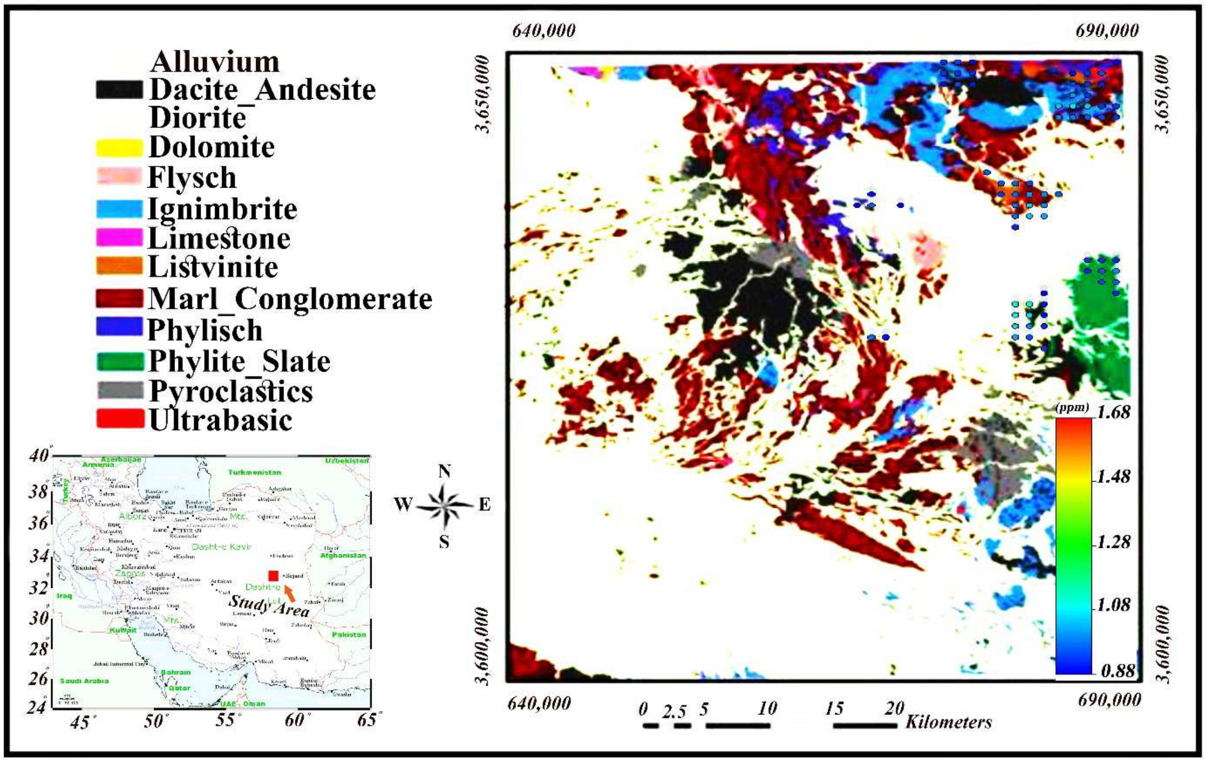

Fig. 10. Location of Cd anomalies in central eastern part and the North Eastern part of 1:100,000 sheet of Khusf.

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