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Application of C-A fractal model and exploratory data analysis (EDA) to delineate geochemical anomalies in the: Takab 1:25,000 geochemical sheet, NW Iran

Ahad Nazarpour*[1]

1. Department of Geology, Ahvan Branch, Islamic Azad University, Ahvaz, Iran

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Abstract

Most conventional statistical methods aiming at defining geochemical concentration thresholds for separating anomalies from background have limited effectiveness in areas with complex geological settings and variable lithology. In this paper, median+2MAD as a method of exploratory data analysis (EDA) and concentration-area (C-A) fractal model as two effective approaches in separation geochemical anomalies, are used to identify geochemical anomalies in the Takab 1:25000 geochemical data sheet by using stream sediment geochemical data and lithogeochemical samples. We compared the anomalous area created using thresholds from various methods on the same data against known deposits and lithogeochemical samples. Results indicated that EDA methods are more impressible by lithology and could not well identify the geochemical anomalies in the areas with variable lithology. On the other hand, the C-A model based on the distinct anisotropic scaling properties, was better in revealing local geochemical anomalies, because it considered the spatial characteristics of geochemical variables.
Keywords: *Geochemical Anomaly, Concentration-Area, Fractal, Takab, Iran*

1. Introduction

A geochemical anomaly could be defined as values greater than a given threshold. Statistical methods based on certain assumption about the underlying statistical distribution of the geochemical data are typically employed in order to determine anomaly threshold values. Statistical quantities such as mean, percentile, and standard deviation could be used to define thresholds for separating anomalies form background. For example, geochemical anomalies could be defined as values greater than a given threshold, such as 75th, 85th percentile, and mean+1Sdev or mean+2Sdev. However, several authors have recognized practical disadvantages of these approaches to anomaly delineation (Harris et al. 1999, Cheng 1999, Qiuming 2000). Conventional statistical methods used for geochemical anomaly separation such as box-plots, cumulative probability plots, quintile-quintile (Q-Q) plots, multivariate and univariate analysis methods (Sinclair 1974, Govett et al. 1975, Sinclair 1976, Miesch 1981, Stanley and Sinclair 1989, Sinclair 1991, Cheng, Agterberg and Bonham-Carter 1996) are primarily concerned with the frequency distributions of element concentration values and relations among multiple variables. The main limitation of the above approaches is that they do not take into account the variability of spatial-statistical distribution of geochemical data. These methods are simple effective for solving some problems but are of limited in situations where this is extensive overlap between background and anomalous values, or where weak anomalous values are hidden within the strong variance of background (Cheng 2007).

Fractal geometry established by (Mandelbrot 1983) is a non-linear geometry and has been widely applied in geoscinces (e.g, Turcotte 1986, Agterberg, et al. 1993, Cheng et al. 1994, Sim et al. 1999, Ali, 2007, Carranza 2008, Deng et al. 2010, Wei and Yang 2010). Several fractal and multifractal models including concentration-area (C-A) (Cheng et al. 1994; Rajabzadeh et al. 2015), spectrum-area (S-A) (Cheng, Xu and Grunsky 2000, Xu and Cheng 2001, Cheng 2004), concentration-distance (C-D) (Li, Ma and Shi 2003), concentration- volume (C-V) (Afzal et al. 2010), number-size (N-S) (Mandelbrot 1983, Agterberg 1995, Deng et al. 2010, Wang et al. 2010), have been developed for application in geosciences, especially geochemical data processing.

In this paper, we focus on identification of geochemical anomalies in the Takab 1:25,000 geochemical data sheet by using stream sediment and lithogeochemical samples. Median +2MAD as exploratory data analysis (EDA) and concentration-area (C-A) fractal model as two effective approaches in separation geochemical anomalies, were used to separation and delineation of geochemical anomalies.

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*Corresponding author.
E-mail addres: Ahad.nazarpour@gmail.com

2. Methods

2.1. Exploratory data analysis (EDA)

In geochemical exploration geochemistry, value of EDA as median+2MAD were originally used to identify extreme values and act as the threshold for further inspection of large data sets (Hawkes and Webb 1962, Zheng et al. 2014; Nazarpour et al. 2016). The EDA was first introduced by Tukey (1976), and then was used by many researchers in modelling of geochemical anomalies (Kürzl 1988, Ali et al. 2007, Carranza 2008, Carranza 2010). The EDA is robust against the non-normality of populations (Kürzl 1988) and includes some descriptive statistical and graphical tools to produce more representative threshold values and generate results that are less effective by the presence of outliers (Carranza 2008; Nazarpour et al., 2015). The MAD is estimated as the median of absolute deviation of all data values for the data median (Tukey 1976).

$$MAD = median\|Xi - median(Xi)\| \qquad (1)$$

where the values in brackets are absolute difference between certain values Xi and median of these values.

2.2. Concentration- Area model

Cheng et al. (1994) proposed the C-A fractal model, which could be used to identify the geochemical anomalies from geological background. The concept of C-A fractal method can be summarized as follows. The C-A method is based upon a very simple empirical set of equations, which may be used to define the geochemical background and anomalies. The model has the general form below:

$$A(\rho \leq \upsilon) \propto \rho^{-a_1}\,;\ A(\rho > \upsilon) \propto \rho^{-a_2} \qquad (2)$$

where $A(\rho)$ denotes the area with concentration values greater than the contour value (ρ), υ is the threshold, a_1 and a_2 are fractal dimensions which are greater than zero (Bai et al. 2010, Nazarpour et al. 2013, Zuo et al. 2013). The two approaches which were used to calculate *A(ρ)* by Cheng et al. (1994) were: (1) The *A(ρ)* is the area enclosed by contour level (q) on a geochemical contour map resulted from the interpolation of the original data using a weighted moving average method, and (2) *A(ρ)* are the values obtained from the results of the box-counting method on the original elemental concentration values. Distinct patterns, each corresponding to a set of similarly shapes contours can be separated by different straight segments fitted to the values of the contours and enclosed areas on log-log plot. The slope of the straight lines can be taken as an estimation of the exponents of the power-law relation in Eq. (2). The optimum threshold for separating geochemical anomalies from background is the concentration value common to both linear relationships on the log-log plot.

3. Geological setting

Continental collision between the Afro-Arabian continent and the Iranian microcontinent during closure of the Tethys ocean in the Late Cretaceous resulted in the development of a volcanic arc and Sanandaj-Sirjan metamorphic zone in NW Iran (Fig 1) (Mohajjel and Fergusson 2000, Karimzadeh Somarin 2005, Ghasemi and Talbot 2006,). These belts were formed by subduction of the Arabian plate beneath central Iran during the Alpine orogeny (Agard et al. 2005). The Takab 1:25000 sheet is located in the eastern part of Takab 1:100000 geological sheet, which is in the NW part of Iran (Nabavi 1976). In two separate time intervals, one during the Late Precambrian–Early Cambrian and the other at Tertiary (Neogene), the prevailing geological conditions, namely, tectonic, magmatic, metamorphic, stratigraphic, and mineralogical characteristics, have made Takab quadrangle one of the most important metallogenic provinces of the country with no compare (Ghorbani 2002). The following mineral deposits and indications occur in Takab quadrangle (Ghorbani 2002):

- Lead–zinc deposits, for example, Angooran, Alamkandi, Poshtkuh, Molla, and Ayghal'e-si with more than 30 million tons of lead–zinc ores.
- Iron, for example deposits, Shahrak, Mirjan, Ghaliche Bolagh, Chehar Tagh, Kuhbaba, and Zafarabad with an estimated reserve of more than 50 million tons.
- Manganese deposits, for example, Dabaklou and Amirabad. Gold, for example, Zarshouran, Agh Dare, Zarinabad, Ghoozlou, and Arabshah gold indication. The investigations show that a minimum of 100 tons of gold must occur at Zarshouran and Agh Dare.
- Antimony, Arsenic, and Mercury deposits, for example, Moghanlou, Agh Dare, and Ghizghapan antimony deposit; Zarshouran arsenic deposits and Arabshah arse-nic indication; and, Shakh–Shakh mercury indication and Qare Dash mercury deposit.
- Copper deposits, for example, Baiche Bagh multimetallic deposit that include copper, lead–zinc, cobalt, nickel, bismuth, etc., and Tataqeshlaqi and Tazekand indica-tions with an estimated 100,000 tons of reserves.

4. Geochemical data

A total of 611 stream sediment samples have been collected from within the 1:25,000 scale Takab geological map sheet by the Geological Survey of Iran (GSI) in 2009. In addition, for validation of the reliability of the results of mapping stream sediments geochemical anomalies and, thus, the effectiveness of the geochemical anomaly separation, 40 lithogeochemical samples for chemical analysis were collected from target areas defined in this study (Fig 2). To evaluate the efficacy of the methods applied, the derived stream sediment geochemical anomalies were compared with the lithogeochemical data for Pb, Zn, Cu, Sn, Mo, W, Ni and Sb obtained by XRF (X-ray fluorescence) and Au, Ag, As and Hg were analyzed by

AAS (flame atomic absorption spectrophotometry). Montana soil as standard reference material (SRM) 2710 was analyzed to assess analytical errors (accuracy 5-10%). Precision were measured by calculating the average difference between duplicate samples (5% of the analyzed samples), is <10%). Geological Survey of Iran (GSI) laboratories carried out analytical geochemical analyses. The statistical properties of the element concentrations in the stream sediment samples are given in Table 1, and the skewness coefficients indicate that the raw data are strongly variable probably due to the diversity of lithology and features such as thrusts, faults, and mineral occurrences.

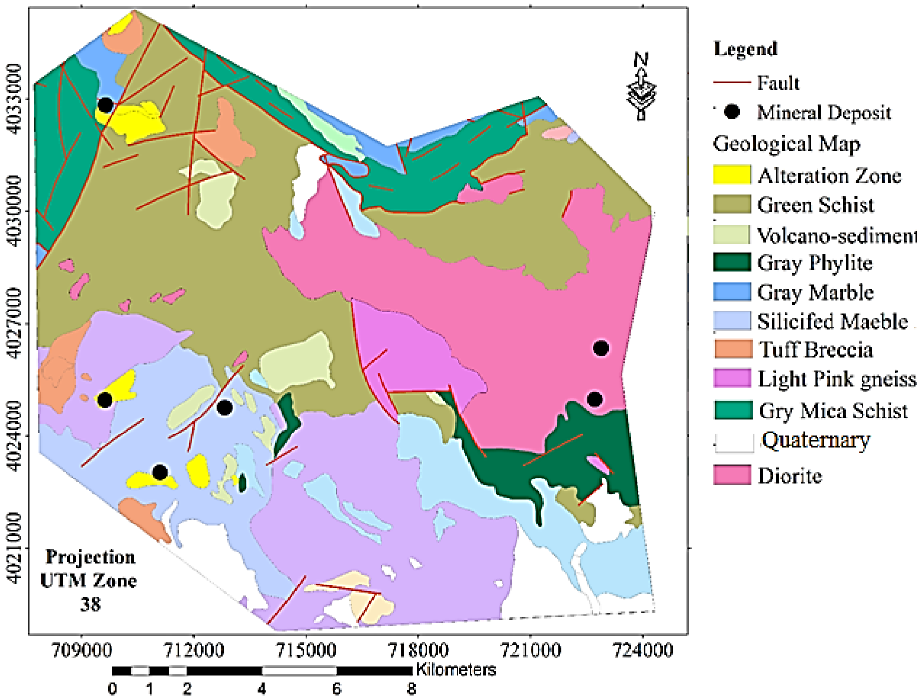

Fig 1. Simplified geological map of study area – the Takab district.

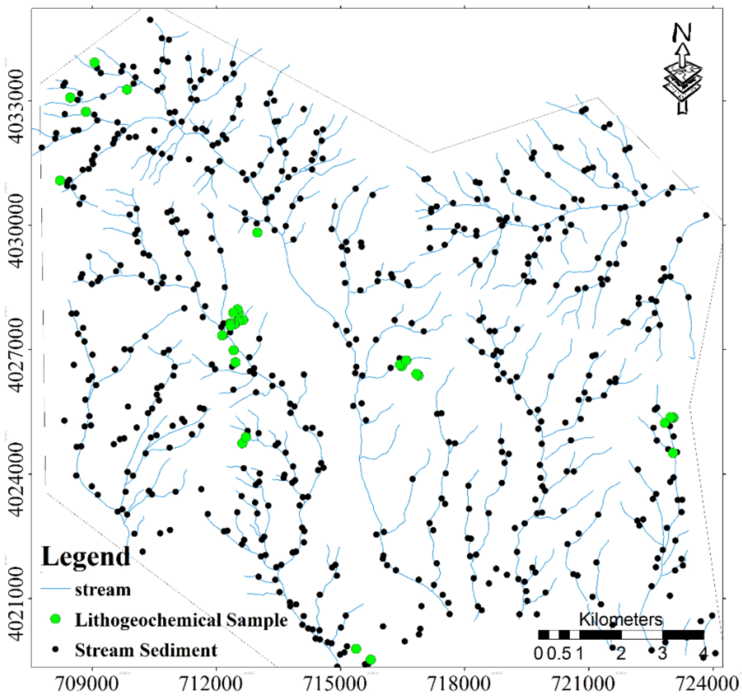

Fig 2. Sampling locations of stream sediments and lithogeochemical samples

5. Results and discussion

Concentration value of Au, Pb, Zn and Cu from 611 stream sediment samples and 40 lithogeochemicals samples were used for mapping and separating the geochemical anomalies in the Takab 1:25000 geochemical sheet. The statistical properties of the concentrations of the target metal elements are summarized in Table 1. Results indicate that the raw dataset is highly spatially variable due to the diversity of geological lithology and features such as thrusts, faults, and mineral concurrency. In order to delineation of geochemical anomalies, we applied median+2MAD as EDA of metal elements and the C-A methods to map and determine the threshold values. Finally, to evaluate the deficiency of threshold-defined methods, the stream sediment geochemical anomalies were compared with the lithogeochemical (rock type) samples.

The median+2MAD method was applied to stream sediment geochemical data to define the threshold and delineate geochemical anomaly domains. The EDA method shows that the defined thresholds are 11 ppb for Au, 80 ppm for Pb, 190 ppm for Zn and 45 ppm for Cu. The different thresholds values were used to map the distributions of metal element concentrations by means of inverse distance weighted (IDW) moving average method (Fig 3a-d). The raster maps of anomalies were compared with Au values of lithogeochemical values for interpretation. The results indicate that there is 73% overlap between the delineated anomalies by median+2MAD method and litogeochemical samples that contained more than 11ppb of Au. 57% overlap for samples that contained more than 80 ppm for Pb, 50% overlap for samples that contained more than 190 ppm for Zn, and 77% overlap for samples that contained more than 45 ppm of Cu. Due to the low threshold values in the EDA method, the aerial proportion of anomalous area covered more than half of study area. The presence of stream sediment geochemical anomalies does not always mean the presence of mineral deposits, and as a result, it is necessary to apply certain criteria or the other methods for screening or prioritization of anomalies prior to any follow-up work.

The C-A method was used as a comparison model for separating of anomalies form background. The Fig 4a-d shows the log-log plots of Au, Pb, Zn and Cu versus area of for the whole of study area. The delineated threshold for Au, Pb, Zn and Cu are shown in Fig 5. Based upon the C-A model, there are three geochemical populations for Pb, Zn, and Cu and two geochemical populations for Au. Breaks between the straight line segments and correspond values have been used as threshold values and reclassify of cell values in raster maps. The thresholds on the anomaly map are indicative of populations, which are interpreted as geological background, moderate and strong anomalies for Pb, Zn and Cu, geological background and anomaly for Au.

Comparing the maps of C-A metal elements anomalies and geological features indicate that these locations coincide with the known deposits such as Chichaklo and Ay-Ghale-Si, also hydrothermal zones and altered marble outcrops, especially in south and northwest and central parts of the Takab area. Correlation results of lithogeocheical samples and anomalous areas, indicate that 23% of lithogeochemical samples with lower values of Au defined by C-A method are located in areas of strong anomaly. In addition, 31% of lithogeochemical samples with high values of Au located in background area. Two class of moderate and strong anomalies are targets for more exploration work. The strong anomalies are mostly associated with outcrops of andesitic, trachyandesitic, grey marbles, and vocanosedimentry rock types. Whereas the moderate anomalies could be related to the hidden mineralization. Results of overlapping analysis of Pb anomalies between stream sediment geochemical data and lithogeochemical threshold defined from C-A method indicate that 68% of lithogeochemical anomalies have lower values than defined thresholds, which located in background and moderate anomalous zones. The high anomaly shows that 32% lithogeochemical samples have greater values than defined threshold, which located in moderate zone and just one sample with high value of Pb fall in strong anomalies. Correlation between the Zn anomalies by C-A method and lithogeochemical samples shows that 90% of samples have lower values than defined threshold and remaining 10% of samples with high values correlate with moderate anomalous area. Correlation results lithogeochemical samples and of the strong anomalies by C-A method indicate that more than 98% of samples have greater values than defined threshold and fall in strong anomaly zone. Finally, results indicate that the median+2MAD model is useful to identify geochemical anomalies within a region with simple geochemical background, but the C-A model shows better results within a region linked with complex geological setting.

Based on the maps obtained, the C-A method illustrates better results than the classical methods because the claasical models is useful to identify the geochemical anomalies within a region with a simple geochemical background but the model has limitations within a region linked with a complex geological setting where each sub-area is characterized by different geochemical fields and the whole region has a complex tectonic setting. When the study area is regarded as a whole mineral district regardless of different geological backgrounds and different geochemical fields in a complex region, the claasical models could not effectively identify the weak anomalies.

Table 1. Statistical parameters of raw data based on stream sediment geochemical sample analysis.

	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness
Au (ppb)	1	94	4.84	8.47	71.895	5.22
Cu (ppm)	8	455	44.49	40.87	1670.85	5.33
Pb (ppm)	3	7544	114.92	488.73	2380.67	10.07
Zn (ppm)	26	6850	266.51	721.24	5201.06	6.23

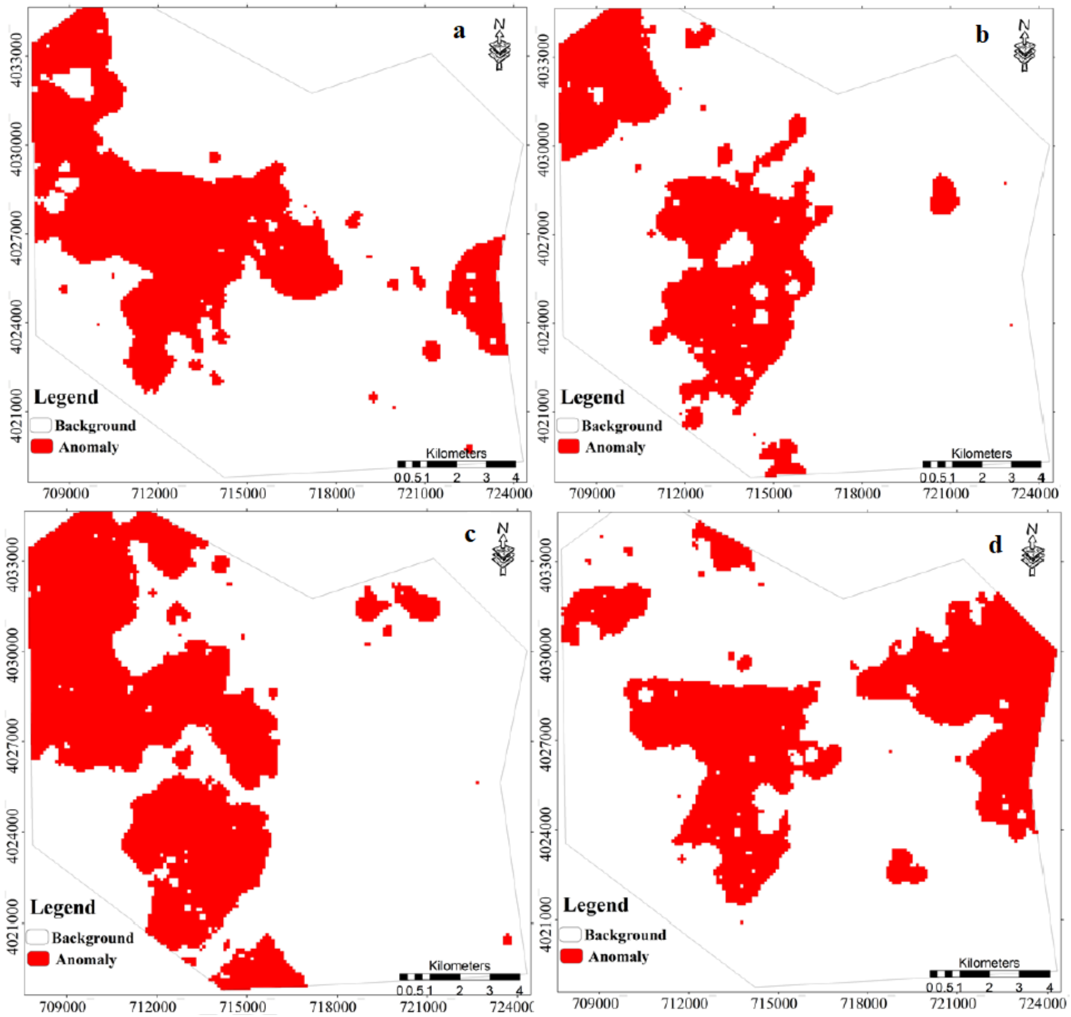

Fig 3. Cu, Pb, Zn and Au anomaly maps of A: Au, B: Pb, C: Zn and D: Cu according to the median+2MAD method

6. Conclusion

The explanation and delineation of geochemical anomalies in the region can provide important information for understanding of ore systems. Results show that the anomalies are well identified by mean of median+2MAD of Au, Pb, Zn and Cu concentrations, and the C-A model. There were very good correlations between calculated anomalous and geological specifics in the Takab area. Delineation of geochemical anomalies based of median+2MAD and C-A methods indicate that the EDA methods are more impressible by lithology and could not well identify the geochemical anomalies in the areas with variable lithology. On the other hand, the C-A model based on the distinct anisotropic scaling properties, was better in revealing local anomalies, because it considered the spatial characteristics of geochemical variables.

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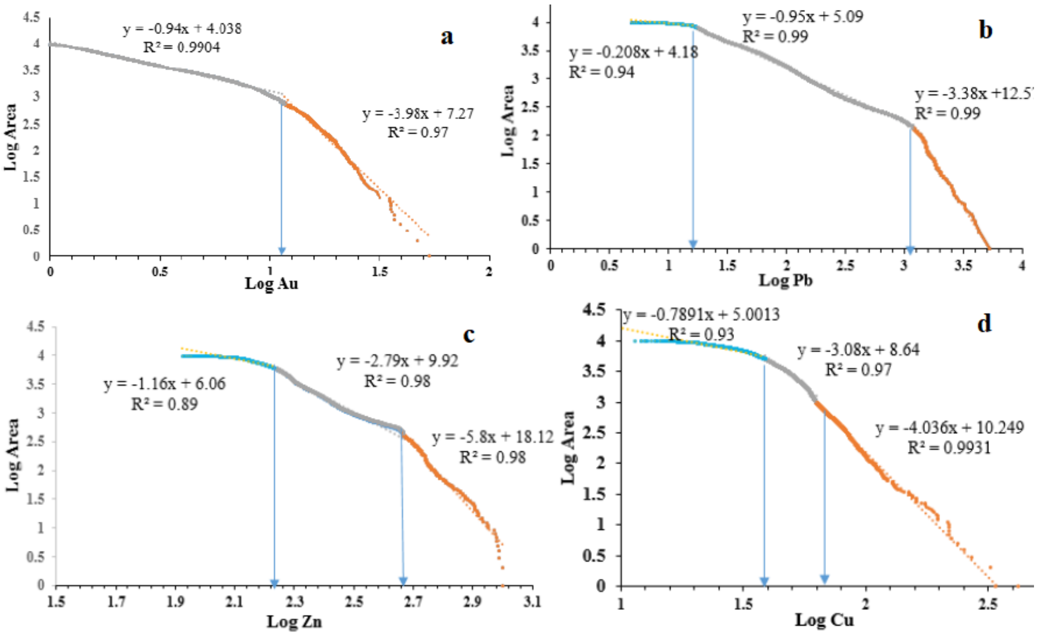

Fig 4. Log-log plots (C-A) method for Au, Pb, Zn and Cu.

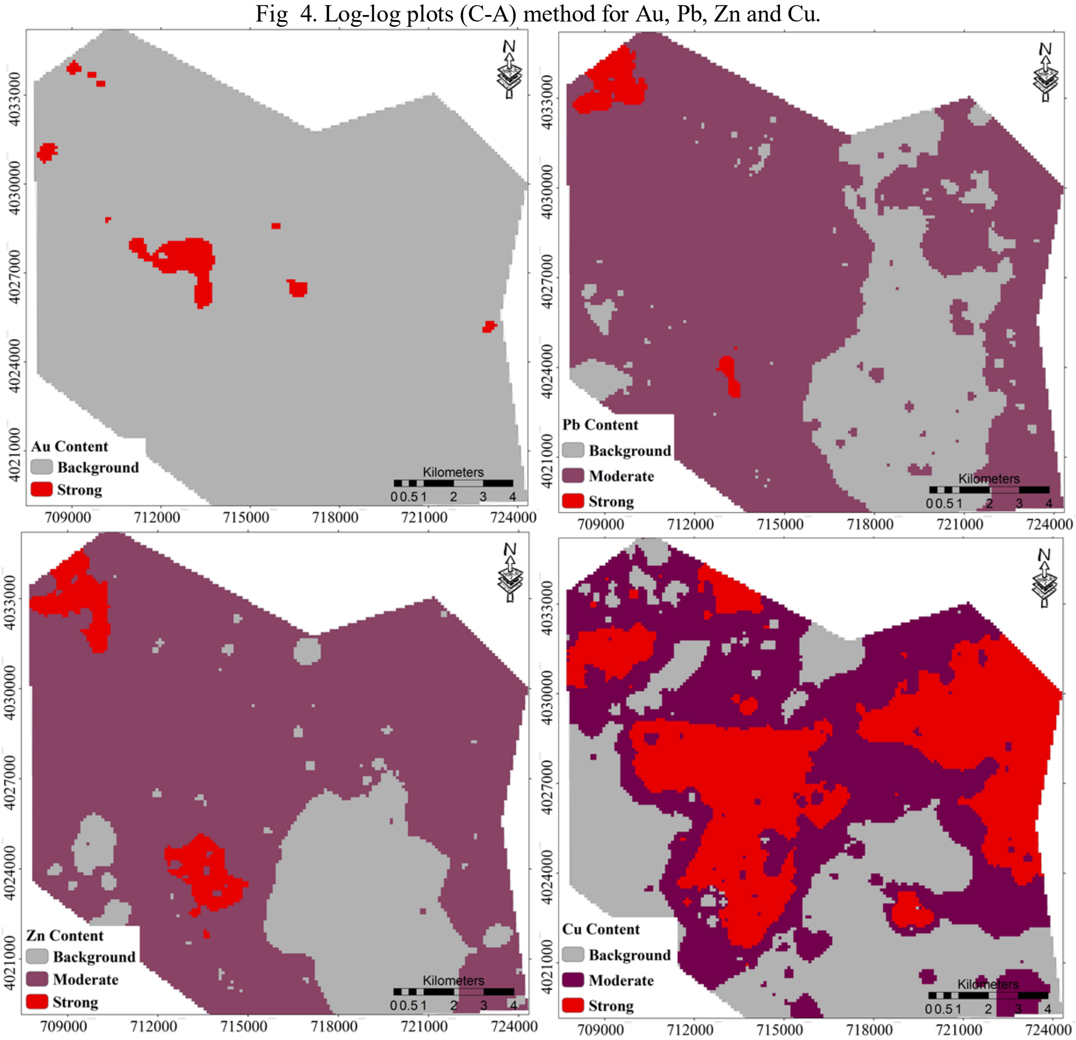

Fig 5. Au, Pb, Zn and Cu geochemical population distribution maps based on C-A method

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