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Delineation of Gas Content Zones Using N-S Fractal Model in Coking Coal Deposits

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Abstract

This work aims to classify the gas content zones for coking coal deposits using a Number-Size (N-S) fractal modeling considering the explosive and free gas data. The case study is the C1 coking coal seam in the Parvadeh-4 coal deposit in the central Iran. Following this, the N-S log-log plots are created, which indicate three populations regarding both the explosive and gas data exist. Proper zones for both data in the C1 coking coal seam have explosive and free gas contents lower than 9.5 m3/ton and 1.3 m3/ton, respectively. The low-value gas content zone is located in the western part of the studied area, which is in the lowest depth of this coal seam. In addition, a high-value content zone exists in the E, NE, and SW parts of this area with explosive and free gas contents higher than 13.8 m3/ton and 2.2 m3/ton, respectively. These parts of the C1 seam are dangerous due to a high volume of gas content. Moreover, the explosive and free gas contents have a positive correlation with high risk gas volume based on the famous standards.

1. Introduction

The gas content evaluation is important for safety and ventilation in the underground coal mines. Estimation and modeling of gas contents including explosive and free gas are significant aspects for this purpose [1-4]. Most of the human fatalities in coal mines in different countries, specifically China and Iran, are associated with these parameters. Therefore, the gas volume of coal seams shows a potentially significant risk for the safety and productivity of coal extraction [5-6]. Based on the global problem, modeling of gas content in a coal seam is an essential operation for the design of an underground mining operation. In addition, coal mining is known as a source of energy and other productions in the world [7-8]. Moreover, gas content of a coal seam, specifically for semi-bituminous coal, can be used for an energy source [4]. Based on these items, modeling of gas content zonation is important for coal deposits, especially coking coals.

Different mathematical methods have been used for modeling zonation of different characteristics in the various ore deposits, especially fractal modeling [9-12]. Fractal methodology, recognized by Mandelbrot (1983) [13] has been commonly utilized in mining engineering, particularly for explanation of spatial distribution of geomechanical data since 1980 [14-17]. A basic model has been innovated by Mandelbrot (1983) [13] entitled Number-Size (N-S) for distinguishing different sectors of natural attributes such as geological data. This method has been used for categorization of natural features such as islands, lineaments, and trees [13]. Other fractal/multifractal approaches such as concentration-area [14], concentration-volume [9],

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and concentration-number have been improved due to this methodology [18]. Their log-log plots have been used for this purpose [9, 13, 14].
In this research work, the N-S fractal technique was practical to achieve explosive and free gas populations for delineation of gas content zones in the C1 seam based on the drillcore data in the Parvadeh 4 coal deposit located in the central Iran.

2. Methodology
2.1. N-S fractal model

This application can be applied to define the situation of geological populations without geostatistical data processing. This model reveals that there is an affiliation between the required characteristics (gas content in this scenario) and their cumulative number of samples. Many developed models have been introduced in order to explain the N-S relationship based on the frequency distribution of regionalized variables [18-22]. To do this, a concentration–number (C-N) model was used to outline the gas content threshold values in this work [18]. This model is stated by the resulting equation [13, 18]:

$$N(\geq\rho) = F\rho^{-D} \quad (1)$$

where ρ and $N(\geq\rho)$ indicate the value of the regionalized variables (e.g. gas content) and the cumulative number of taken samples with attribute amounts more than or equal to ρ, respectively, F is a constant, and D is the fractal dimension for distribution of the gas content in this scenario. The log-log graphs of $N(\geq\rho)$ against ρ illustrate straight line sectors with various slopes $-D$ according to different ρ intervals.

2.2. Case study

Coking coal resources are about 7-10 Gt in Iran. They are principally within two basins in the north and central Iran named as Alborz and Central basins, respectively [23]. The Tabas coalfield hosts the main Iran's coking coal with reserves between 3 and 4 Gt [23, 24].

The Parvadeh 4 coal resource is situated around 80 km south of the city of Tabas (Figure 1). The Tabas coalfield region is separated into various sub-zones including Parvadeh, Nayband, and Mazinu. The Parvadeh district consists of six sections that are separated by main faults. The Parvadeh 4 coal deposit is divided by the NE-SW faults from Parvadeh 3 and East-Parvadeh, as shown in Figure 1. The coal-bearing strata of the Tabas coalfield principally consists of the Upper Triassic and Middle Jurassic sediments, specifically for the Nayband formation and the Ghadir member. The rock types consist of sandstone, siltstone, shale, sandy siltstone, and small amounts of limestone and coal with high values of ash. The coal seams in Parvadeh are A, B, C, D, E, and F. It has been noted that the B2 and C1 coal seams have an appropriate quality and quantity for coal mining. The C1 seam is the main layer for extraction of coal based on its thickness, geochemical properties, and depth.

3. Statistical analysis

In this research work, 27 samples were collected from 27 boreholes, and were analyzed by the Tabas Coal Co. (Iran). The grid drilling map of these boreholes is presented in Figure 2. The mean and median for explosive gas are 12.8 m^3/ton and 12.5 m^3/ton, respectively. These values are high, which reveal that there is a high content of explosive gas in the C1 seam. Furthermore, the explosive gas and free gas frequency distributions are not normal with respect to their histograms (Figure 3). Moreover, the average and median of the free gas are equal to 1.5 m^3/ton and 1.3 m^3/ton, respectively. The histogram of the free gas shows an abnormal distribution (Figure 3). Based on the abnormal distributions for both data, median is an index for separation of the main population for the high gas content zone. In addition, summation of median and standard deviation can be used for delineation of different levels of gas contents in this deposit. The threshold values for explosive gas are 12.5, 17.9, and 23.3 m^3/ton. Furthermore, the threshold values for free gas content are equal to 1.3, 2.6 and 3.9 m^3/ton.

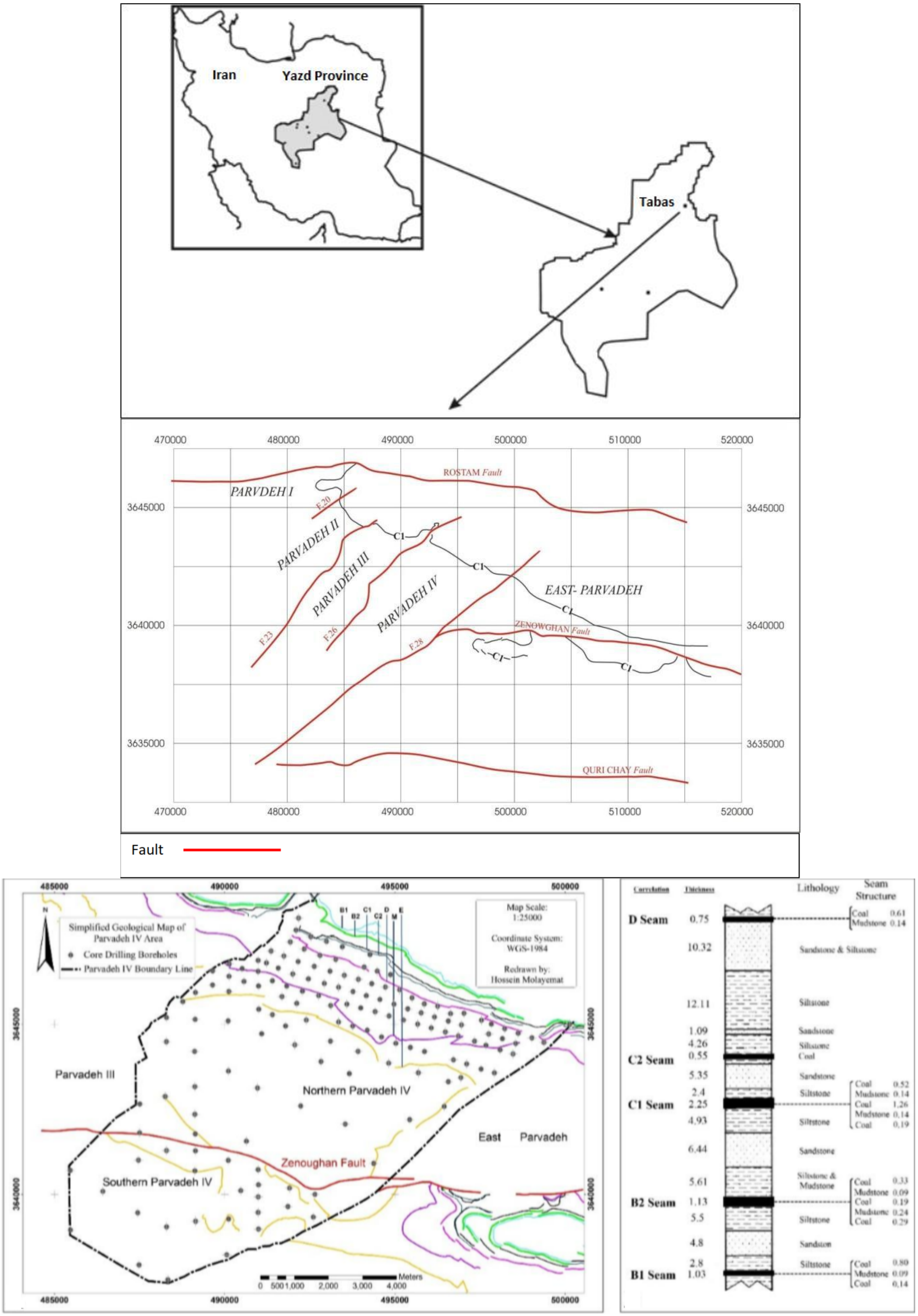


Figure 1. Parvadeh 4 coking coal deposit in the Tabas coalfield [23], and a simplified geological map [25].

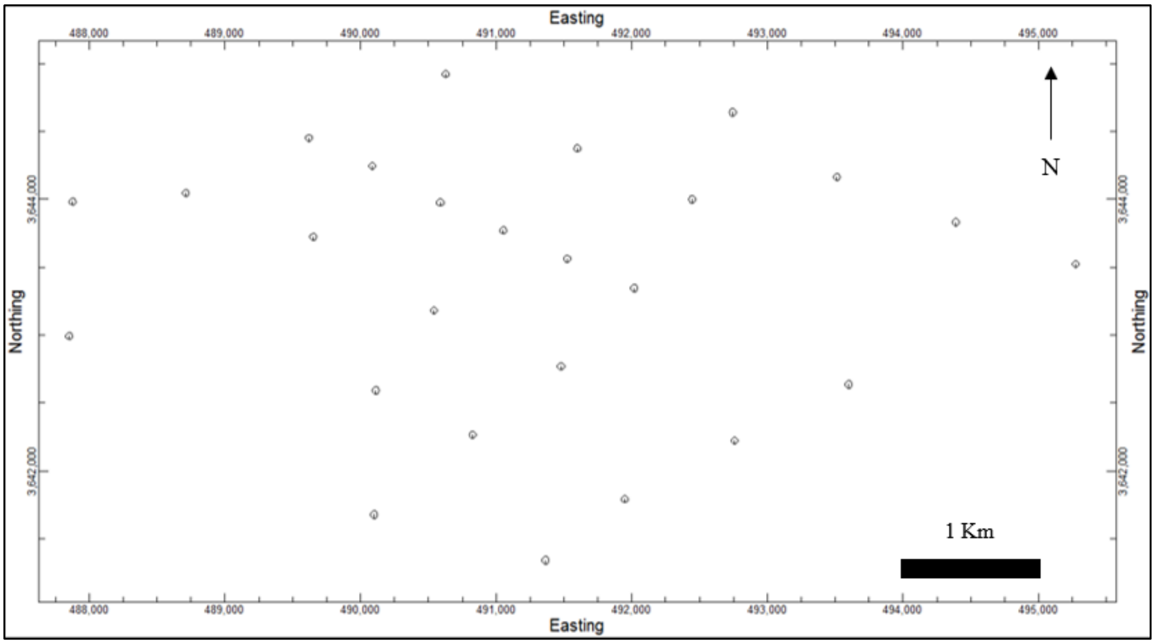
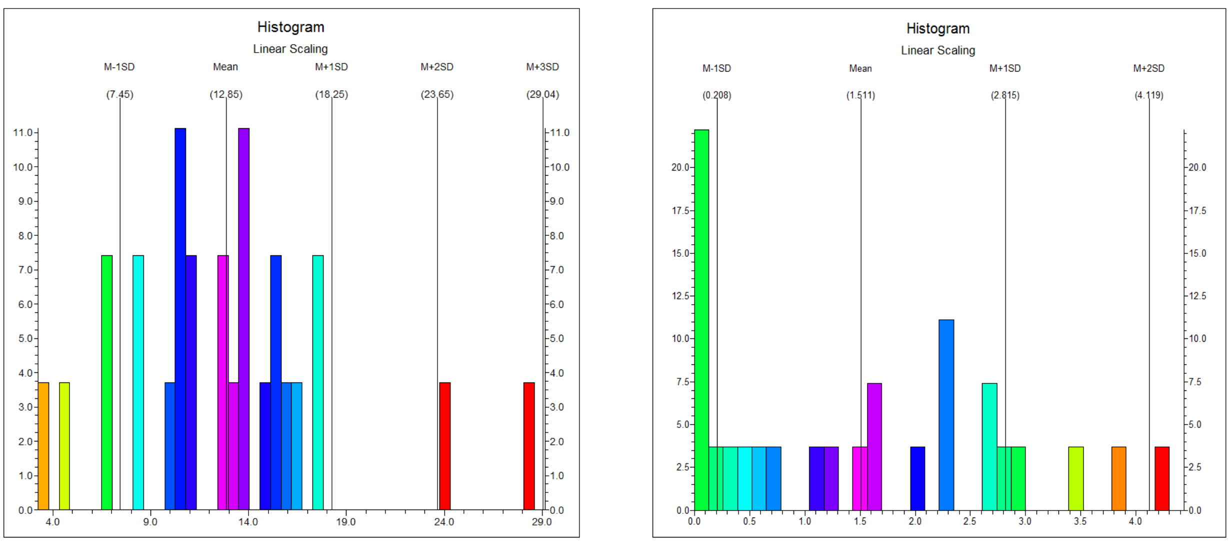


Figure 2. Location of boreholes for gas sampling in Parvadeh 4 deposit.



(a) **(b)**

Figure 3. Histograms of explosive gas (a) and free gas (b).

4. Application of fractal model

According to the N-S log-log plots for the explosive and free gas content data, there are three populations for both datasets (Figure 4). The threshold values and ranges of different populations for gas contents are shown in Table 1. Based on this table, the high-value content zones for the explosive and free gas contents commence from 13.8 m^3/ton and 2.2 m3/ton, respectively. However, the low-value content zone includes the explosive and free gas contents lower than 9.5 m^3/ton and 1.3 m^3/ton, respectively (Table 1). In addition, the moderate-value content zones for the explosive and free gas contents vary 9.5-13.8 m^3/ton and 1.3-2.2 m^3/ton, respectively.

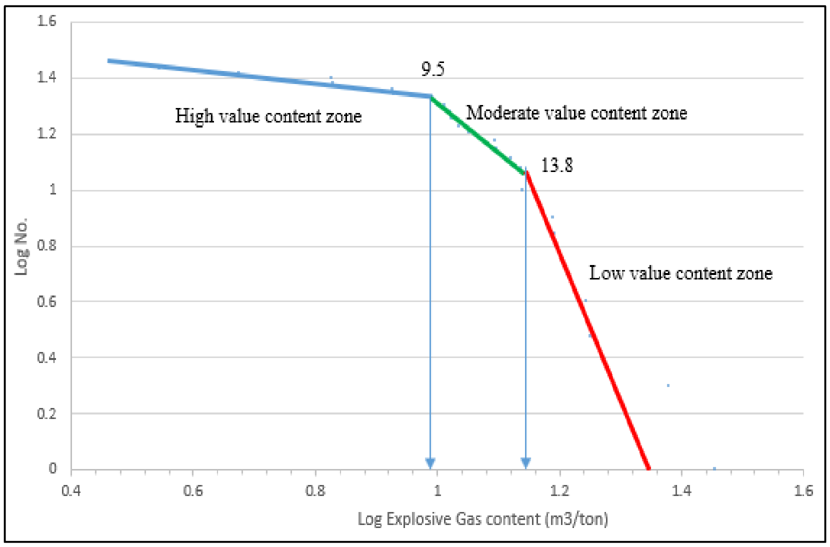
The distribution maps for the explosive and free gas contents were created using the ordinary kriging algorithm by the RockWorks 15 software Figure 5). The cell dimension was determined to be 200 m × 200 m in the Parvadeh 4 deposit according to the distances of the samples taken. The main gas content zone with explosive and free gas contents higher than 13.8 m^3/ton and 2.2 m^3/ton, respectively, is situated in the eastern and SW parts of the C1 coal seam with a high depth (Figure 5).

Therefore, this is a problematic issue and requires an appropriate ventilation system. However, a proper gas content zone consisting of ≤ 9.5 m^3/ton and ≤ 1.3 m^3/ton for the explosive and free gas contents, respectively, is located in the western part of this coal seam (Figure 5).

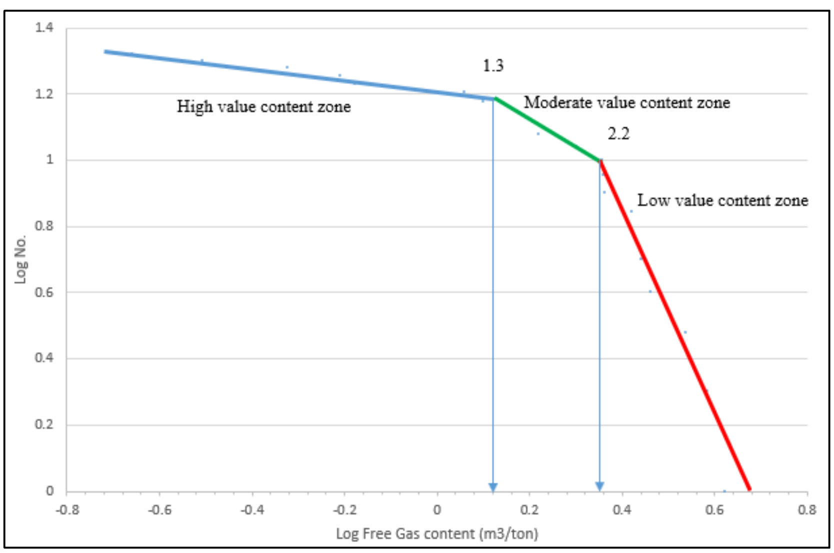
The results of this research work were compared with the ASTM D388 [26] and Russian [27] standards, indicating that the eastern and southern parts have a massive risk based on the summation of gas contents (explosive and free gas contents). There are more than 15 m^3/ton of the gas content in these parts of the coal deposit. Consequently, a high value content zone obtained by fractal model has a proper correlation with high risk gas volume based on the both famous standards.

Table 1. Range of gas content zone in Parvadeh 4 based on the N-S fractal model.

	Low-value content zone	Moderate-value content zone	High-value content zone
Explosive gas (m^3/ton)	≤ 9.5	9.5-13.8	≥ 13.8
Free gas (m^3/ton)	≤ 1.3	1.3-2.2	≥ 2.2

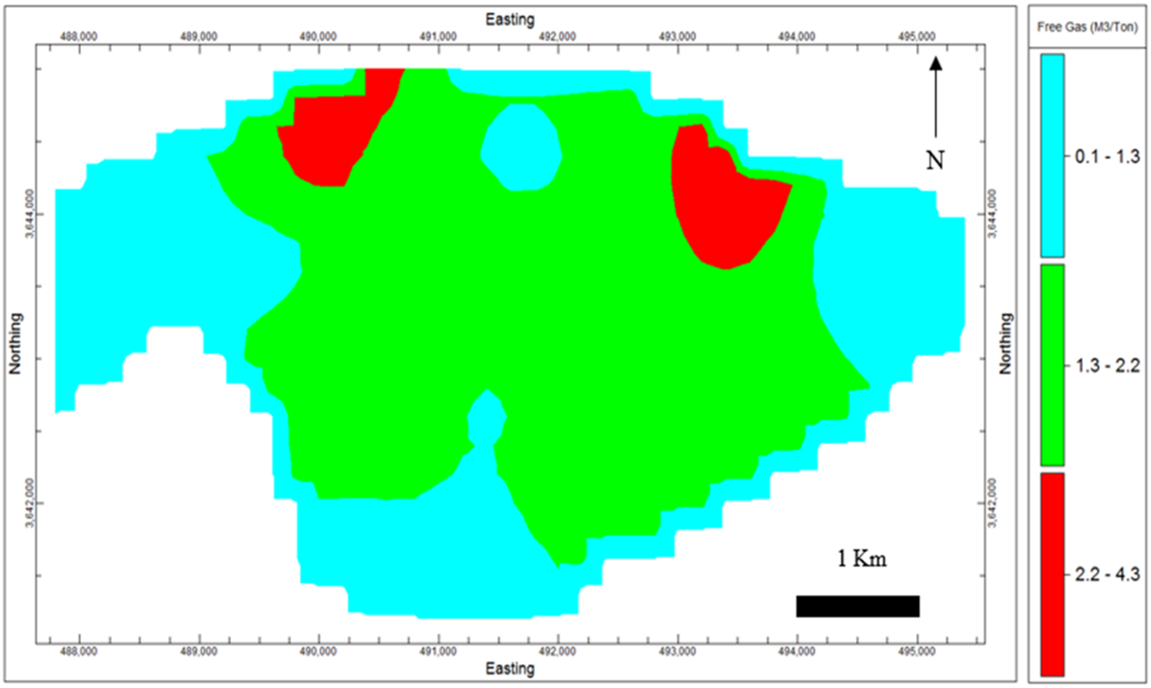


(a)

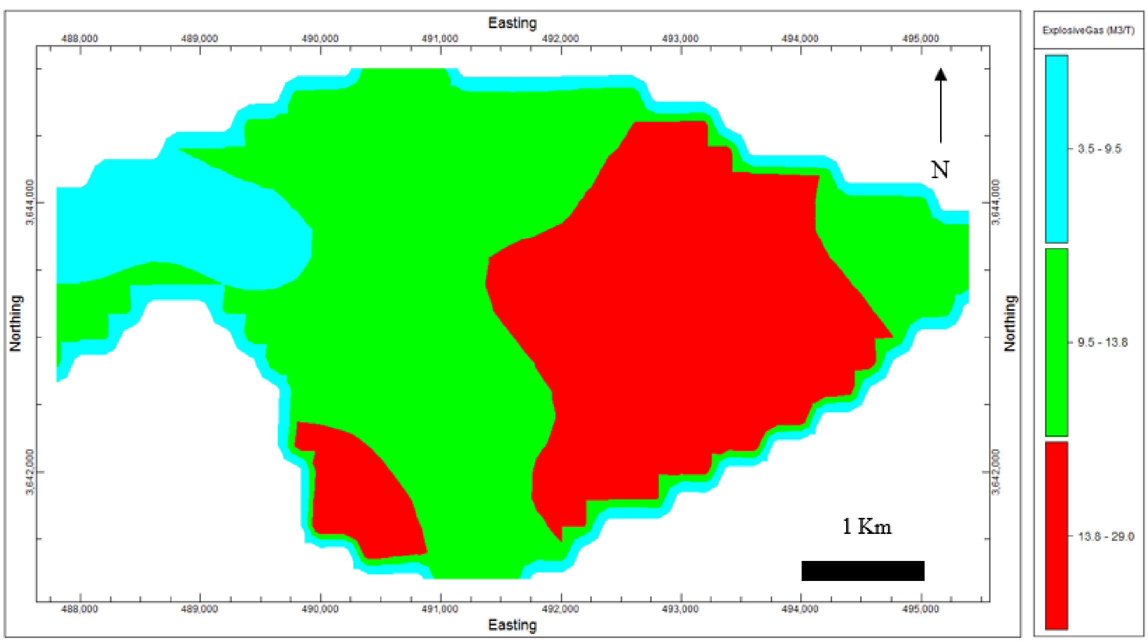


(b)

Figure 4. N-S log-log plots of explosive gas content (a) and free content (b) in the studied deposit.



(a)



(b)

Figure 5. Distribution illustrations resulting from the N-S fractal model for free gas (a) and explosive gas (b) in the Parvadeh 4 deposit.

5. Conclusions

The results of this work reveal that an N-S fractal methodology is proper for detection of different gas content zones. The results derived by the N-S fractal model exhibit a low-value gas content zone, which is in the western part of the area. Additionally, the distribution map of the gas content for the C1 coal seam represents a gas content more than 15 m^3/ton, pertaining to the over-class gas content group in the eastern and SW parts, especially adjacent to the F28 fault and East-Parvadeh area. This can be related to the coal formation in this deposit. There are semi-bituminous coals with significant values of different materials, and also the depth of this coal seam is high in the high-risk parts. A suitable part of the C1 coal seam according to the fractal modeling is located in the western part and close to Parvadeh 3 and the F26 fault. This work represents that this approach is effective for modeling of gasification, and of course, following mine planning and equipment selection for ventilation in underground mines.

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توصیف زون‌های محتوی گاز با استفاده از روش فرکتالی تعداد-اندازه در کانسارهای زغال سنگ کک‌شو

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چکیده:

هدف این پژوهش، رده‌بندی زون‌های محتوی گاز در کانسارهای زغال‌سنگ کک‌شو با استفاده از روش فرکتالی تعداد-اندازه و براساس مقادیر گازهای آزاد و قابل انفجار است. مطالعه موردی لایه C_1 بعنوان لایه اصلی در کانسار پروده ۴ طبس است. در ادامه نمودارهای فرکتالی تعداد-اندازه تولید شده و برای هر دو نوع گاز آزاد و نیز قابل انفجار سه جامعه را نشان دادند. زون‌های مناسب با گازخیزی قابل قبول در این لایه شامل بخش‌های دارای گاز آزاد و نیز گاز قابل انفجار به ترتیب با مقادیر کمتر از ۱/۳ و ۹/۵ تن بر مترمکعب می‌باشند. این بخش‌ها در غرب لایه و همسایگی پروده ۳ هستند که دارای کمترین عمق در منطقه موردمطالعه است. همچنین زون‌های خطرناک و دارای بالاترین مقادیر گاز در بخش‌های خاوری، شمال خاوری و جنوب باختری لایه موردمطالعه قرار دارند. میزان گاز آزاد و قابل انفجار محتوی در این زون خطرناک به ترتیب بیش از ۲/۲ و ۱۳/۸ مترمکعب بر تن است که مطابق با گازخیزی فوق طبقه بوده و نیاز مبرم به تهویه در این بخش‌ها جهت جلوگیری از انفجار معدن وجود دارد. این مقادیر با میزان گاز با خطر بالای انفجار در استانداردهای معتبر جهانی مطابقت دارد.

کلمات کلیدی: زون محتوی گاز زغال، روش فرکتالی تعداد-اندازه، لایه C_1 زغال، کانسار پروده ۴.