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Comparing ordinary kriging and advanced inverse distance squared methods based on estimating coal deposits; case study: East-Parvadeh deposit, central Iran

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Abstract

Finding a proper estimation method for ore resources/reserves is important in mining engineering. The aim of this work is to compare the Ordinary Kriging (OK) and Advanced Inverse Distance Squared (AIDS) methods based on the correlation between the raw and estimated data in the East-Parvadeh coal deposit, central Iran. The variograms and anisotropic ellipsoids are calculated to estimate the ash and sulfur distributions by the IDS and OK methods. The results obtained by these techniques show that their correlation coefficients are similar for the raw and estimated data. However, the statistical parameters obtained by the AIDS method are better based on the ash and sulfur means, although the variance of these variables is lower according to the OK method. The results obtained indicate that the AIDS method yields more reliable results than the OK method.

Keywords: *Advanced Inverse Distance Squared, Ordinary Kriging, Coal, East-Parvadeh.*

1. Introduction

Geostatistical estimation of mineral grades is essential for the design of a mine extraction plan. Evaluation of the elemental grade distribution is an important factor for mine planning and design [1, 2]. A significant item in mining engineering is the estimation of a regional variable (e.g. ore grade in this scenario) in a studied deposit from the observations made at known locations in the deposit/mine. Several methods have been proposed for the operation such as the linear/non-linear kriging, Inverse Distance-Weighted (IDW), nearest neighbor, and conventional geometrical methods [3]. Various interpolation techniques have been compared and validated based on the relative accuracy of their results. In many cases, a kriging process has been introduced as the best estimator [4], although the IDW method has yielded proper results in many studies, especially in sedimentary deposits [4, 5].

Recognition of coking coal parts in the bituminous coal seams is necessary for mine planning and equipment selection for coking coal production. In addition, ash and sulfur distributions are significant for determination of appropriate coal parts in a coal seam for coke production regarding coal washing and environmental control of coal mining [6, 7].

The aim of this work was to evaluate and compare the accuracy of two customized interpolation methods consisting of Advanced Inverse Distance Squared (AIDS) and Ordinary Kriging (OK) based on a geochemical analysis of drill cores in the East-Parvadeh coal deposit, central Iran.

2. Methodology

A geological 3D model of the coal seams is generated using the RockWorks™ v. 15 software, and the surface/subsurface data is collected from the surface outcrops and drillcores. The data includes collar coordinates of drill holes, azimuth and dip (orientation), stratigraphy, and sulfur and ash values for the coal seam cores. Additionally, other surface data consist of topographical data, faults, outcrops of coal seams, and other geological features that are required to construct the 3D geological model. Coal seams are detected in all the cores with respect to geological logging consisting of petrographic and mineralogical studies. In this work, the data for C_1 seam was collected from 87 drillcores including 87 samples for ash and sulfur values.

2.1. Ordinary Kriging (OK)

Kriging has been introduced as a geostatistical methodology for estimation of different regional variables (elemental concentrations, in this case), which is usually defined as a "minimum variance estimator" [8]. A popular geostatistical method is OK, which plays a superior role due to its compatibility with a stationary model that contains a variogram [9]. Furthermore, the OK estimator is a linear model with respect to the local neighborhood structure. This is based upon a moving average for the studied variable of importance satisfying various dispersion forms of data (e.g. sparse sampling points) [10].

2.2. AIDS

IDS is one of the common methods used for interpolation of scatter points/cells in a block model. Advanced Inverse Distance Squared (AIDS) estimates voxel values (e.g. ore grade) by averaging the values of sample data points in the neighborhood of each processing voxel. AIDS has a fundamental assumption that the interpolating surface is mostly influenced based on the distance of points. The interpolating surface is a weighted average of the scatter points, and the weight assigned to each scatter point diminishes as the distance from the interpolated point to the scattered point increases [4, 11].

Major disadvantages of the conventional IDW methods are selection of the weighting function (which may present ambiguity), specifically (where a fixed search radius involves a neighborhood distance), and a maximum or minimum number of points. Moreover, all points will be utilized, which increase error in the form of over- and under-estimation [11]. Thus variography and anisotropic ellipsoid are used in AIDS for a better estimation.

3. Geological setting

The Iranian coking coal resources and reserves, which are principally situated in two major basins in the northern and central Iran, namely the Alborz and Central basins, respectively, have been calculated to be about 7-10 Gt [12]. The Tabas coalfield contains 3-4 Gt resources/reserves, and there are some main coal mines there [12].

The East-Parvadeh coal deposit is located about 80 km south of the Tabas region, central Iran (Figure 1). The Tabas coalfield district is a part of the central Iran structural zone that is separated into various sub-zones, namely Parvadeh, Mazinu, and Nayband. The Parvadeh district consists of six parts divided by major faults, as depicted in Figure1. The East-Parvadeh coal deposit is divided by the Zenoughan fault into the North and South blocks. According to the dip, depth, and structural effects, the North block includes a better quality coal seams than the South block [13]. The major rock types are siltstone, sandstone, shale, sandy siltstone, and small amounts of limestone and ash coal that is coal with high values of ash. The coal seams in the Parvadeh region are named as A, B, C, D, E, and F; it is worth noting that the B and C coal seams are minable based on their quality and quantity, specially the C_1 and B_2 seams that have better qualities (Figure 2). The triangulation algorithm was used for coal seam modelling and after 3D modelling of coal seams, showing that coal seams are deeper in the SW part of the area (Figure 2).

4. Discussion

4.1. Pre-processing of data

In this research work, the AIDS method was used based on variography and anisotropic ellipsoid. Dimensions of the Grid Drilling network were 800 × 800 m, although the network content of 71 drilled holes and 71 samples were from the C_1 seam. These samples were analyzed by the XRF method in the Tabas Coal Company laboratory. For quality control (QC) and quality assurance (QA), 10 duplicate samples were collected, and the results obtained were interpreted by the T-student and Fisher tests. The statistical parameters were calculated for the raw data, and their histogram results for ash and sulfur are depicted in Figure 3. The mean values for the ash and sulfur values were 25.56% and 1.968%, respectively. Then the ash and sulfur values were calculated for the AIIDS and OK methods. These results were compared based on the correlation coefficients between the raw and estimated data in the East-Parvadeh coal deposit, central Iran.

The Variogram models and anisotropic ellipsoid are essential for spatial estimation and interpolation, which are the fundamental components for geostatistical modeling [14]. In this work, the directional variograms for sulfur and ash were created using the RockWorks software in the East-Parvadeh deposit, as shown in Figure 4. Finally, the anisotropic ellipsoid was generated for ash and sulfur (Figure 4). Based on the grid drilling dimensions and type of the ore deposit (thin coal seam), voxel sizes were 200 m × 200 m × 0.2 m according to David (1970) [2]. The minimum and maximum numbers of the points involved in estimation are the important for valuation of each voxel [13]. Based on this item, the minimum and maximum numbers were 3 and 8 points.

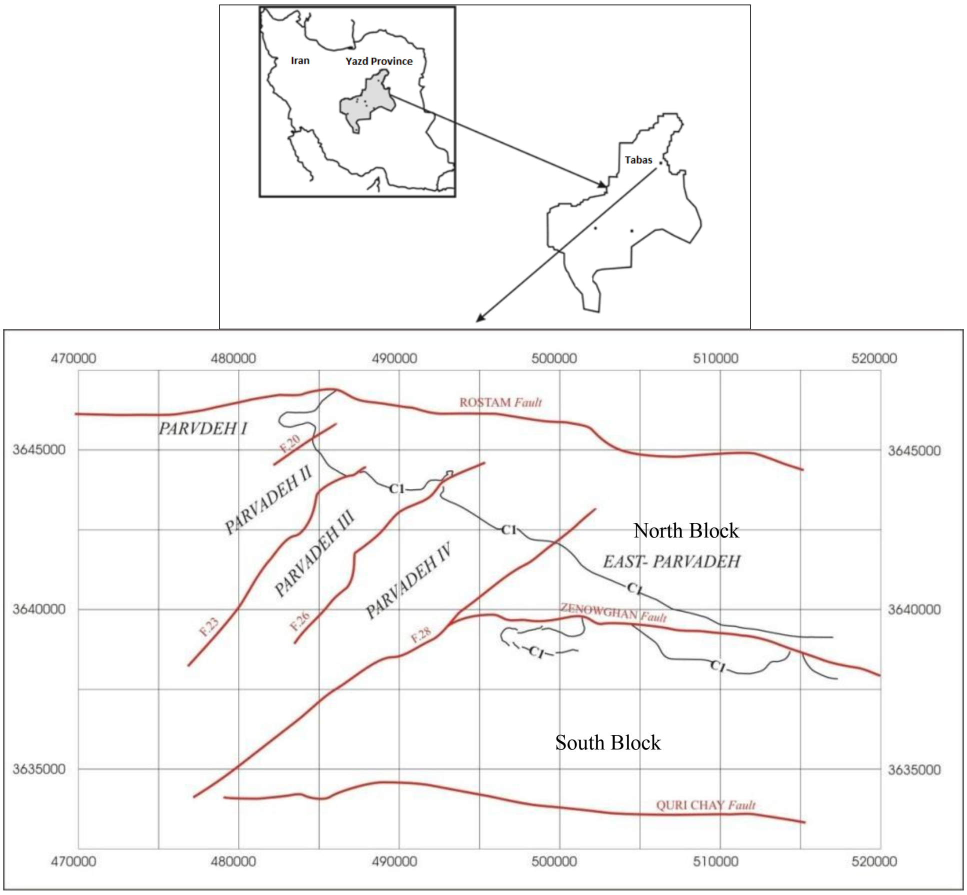


Figure 1. Location of Parvadeh deposits and East-Parvadeh blocks in Tabas coalfield [13].

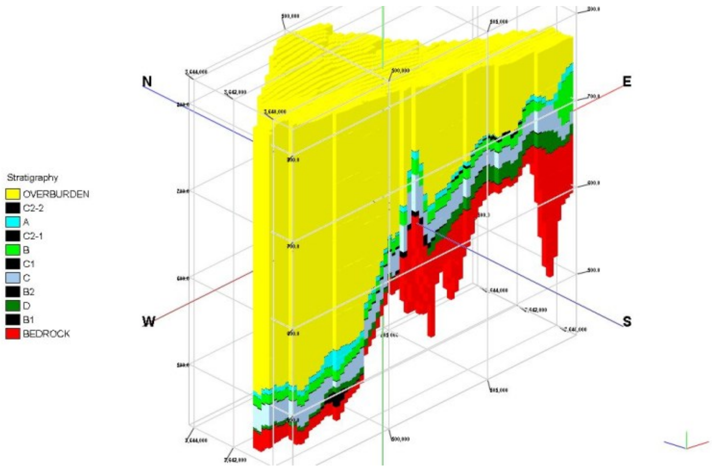
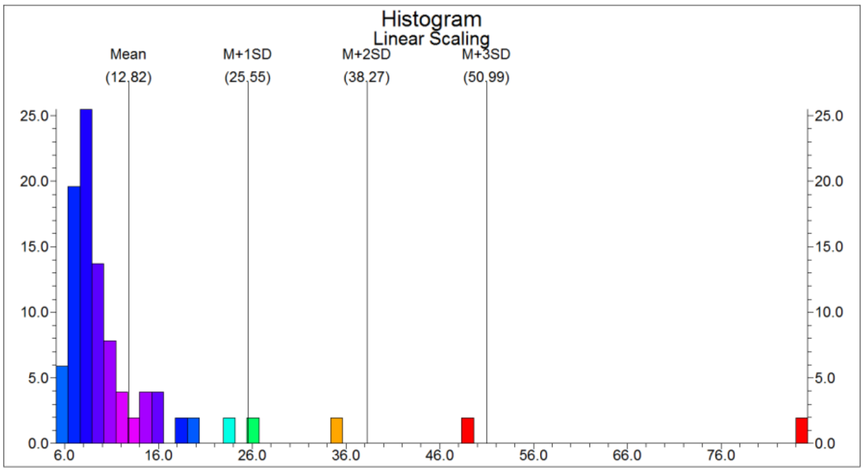
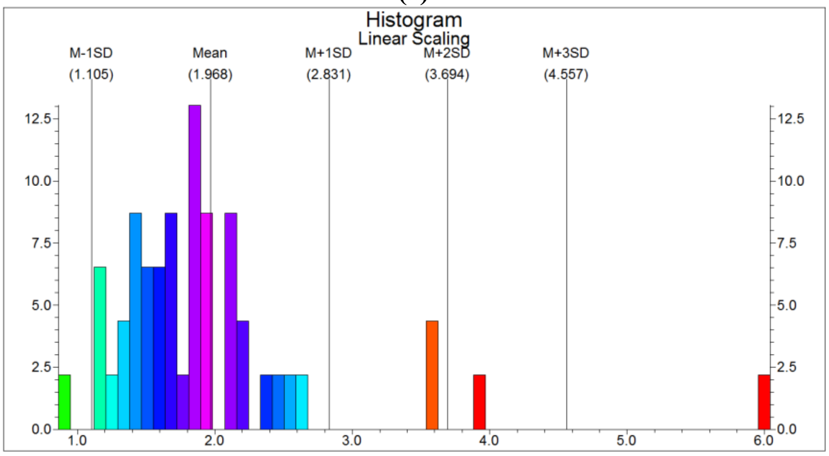


Figure 2. A 3D geological model for the East-Parvadeh deposit with a vertical exaggeration equal to 30 [13].

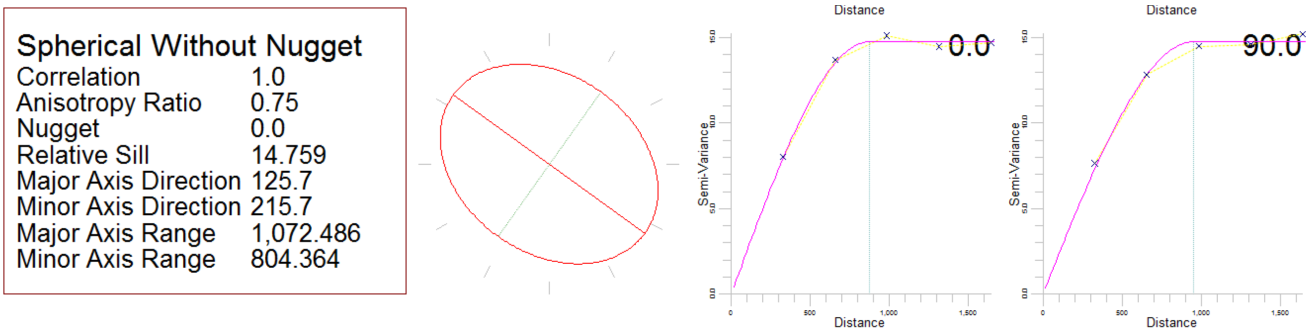


(a)

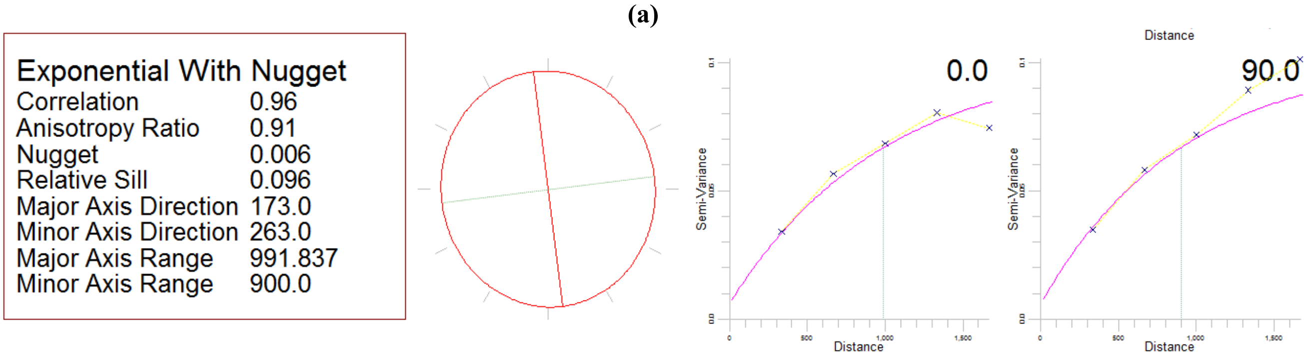


(b)

Figure 3. Histograms for ash (a) and sulfur (b).



(a)

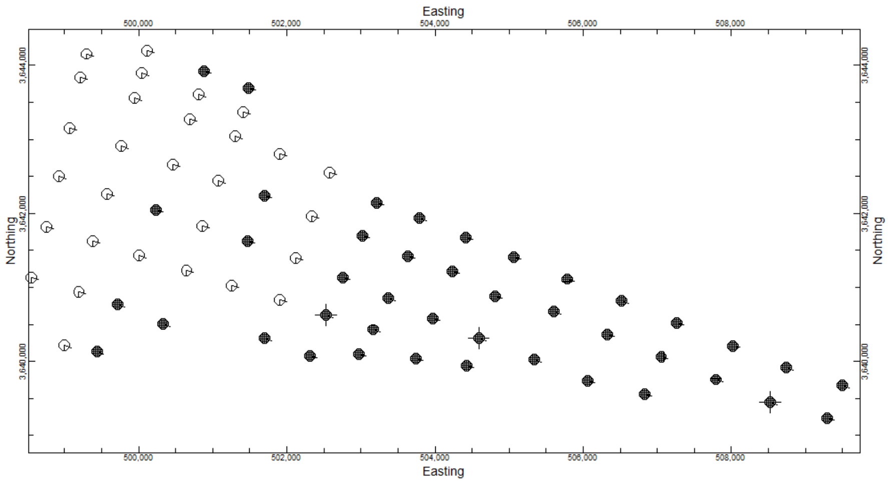


(b)

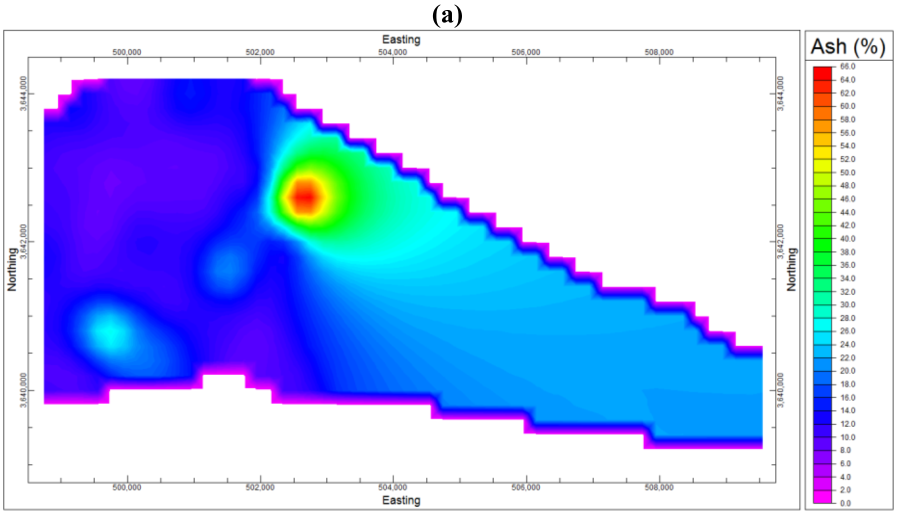
Figure 4. Variograms and anisotropic ellipsoid for ash (a) and sulfur (b).

4.2. Evaluation by OK and AIDS

After pre-processing of the data specifically, variography, the ash and sulfur values were estimated in the deposit by the OK and AIDS methods (Figures 5 and 6). According to the values obtained for both method, high sulfur values were observed in the SW area. However, high grade parts for ash occured in the northern and eastern parts of this deposit. Generally, the results obtained by these estimation methods are not similar. The results obtained for the OK method show a smoothing with a maximum lower than that for the AIDS method.



(a)



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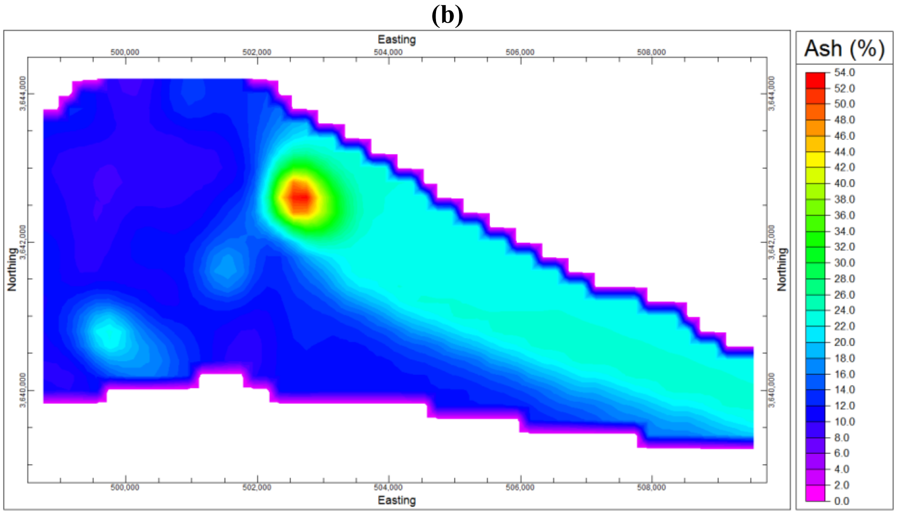
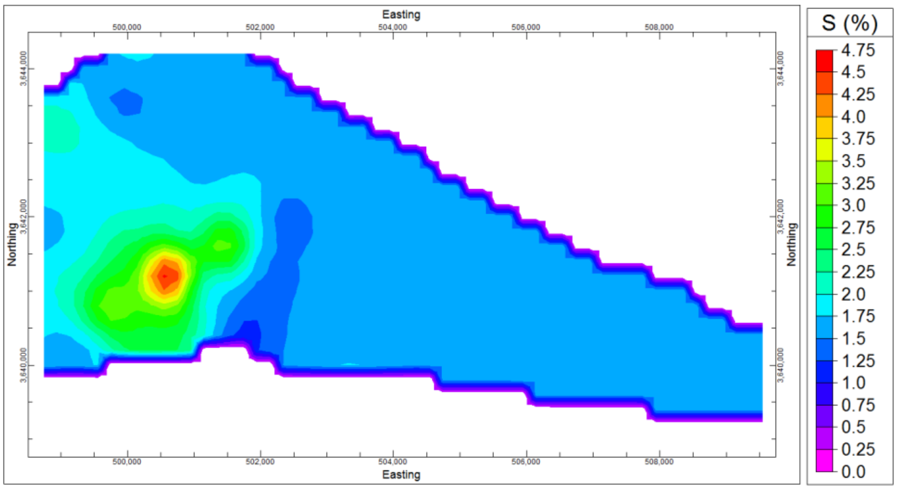
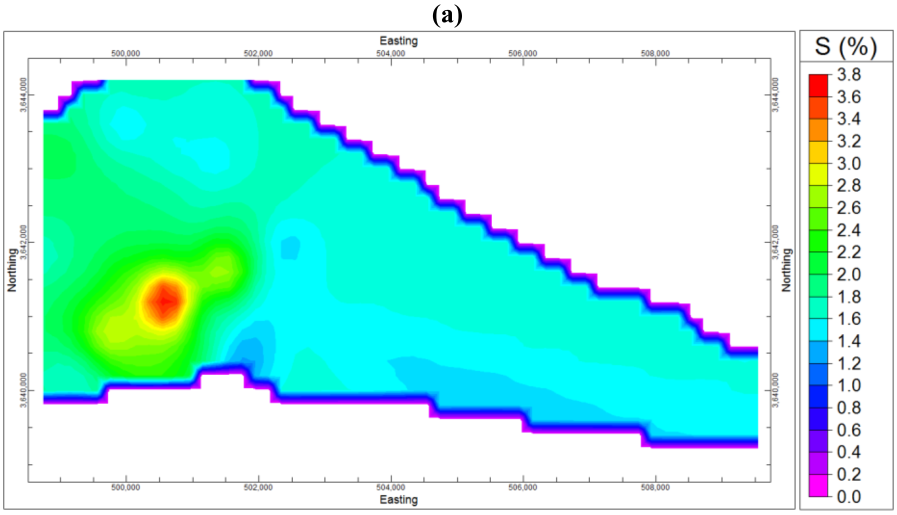


(c)

Figure 5. Location of drilled holes (a) and ash distribution maps based on AIDS (a) and OK (b).



(a)

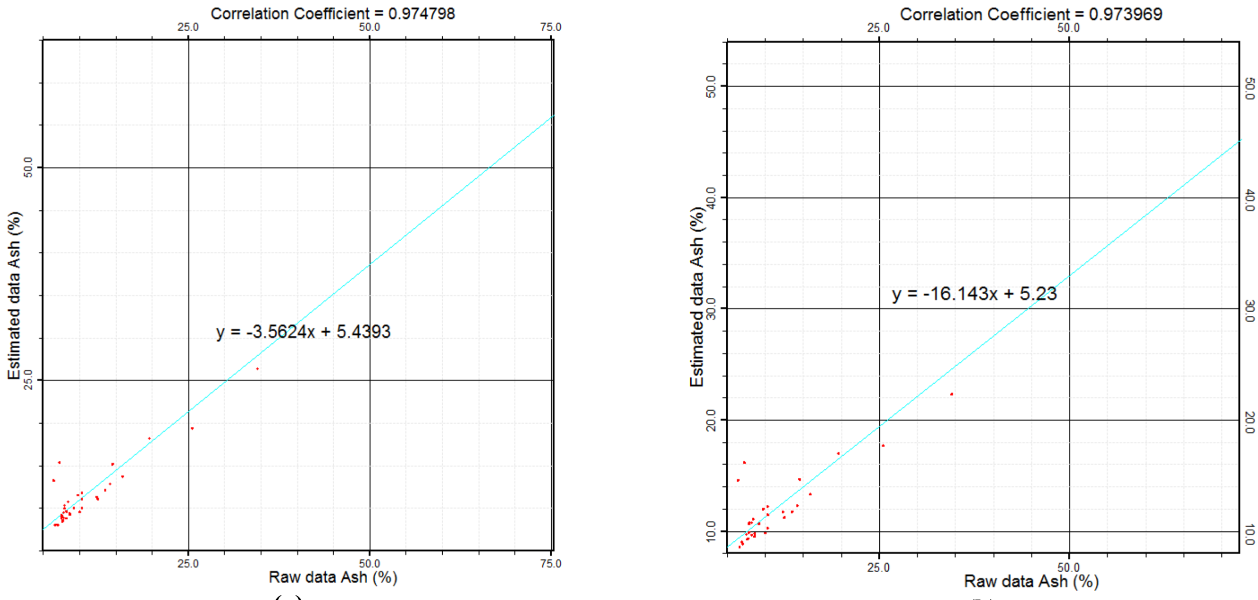


(b)

Figure 6. Sulfur distribution maps based on AIDS (a) and OK (b).

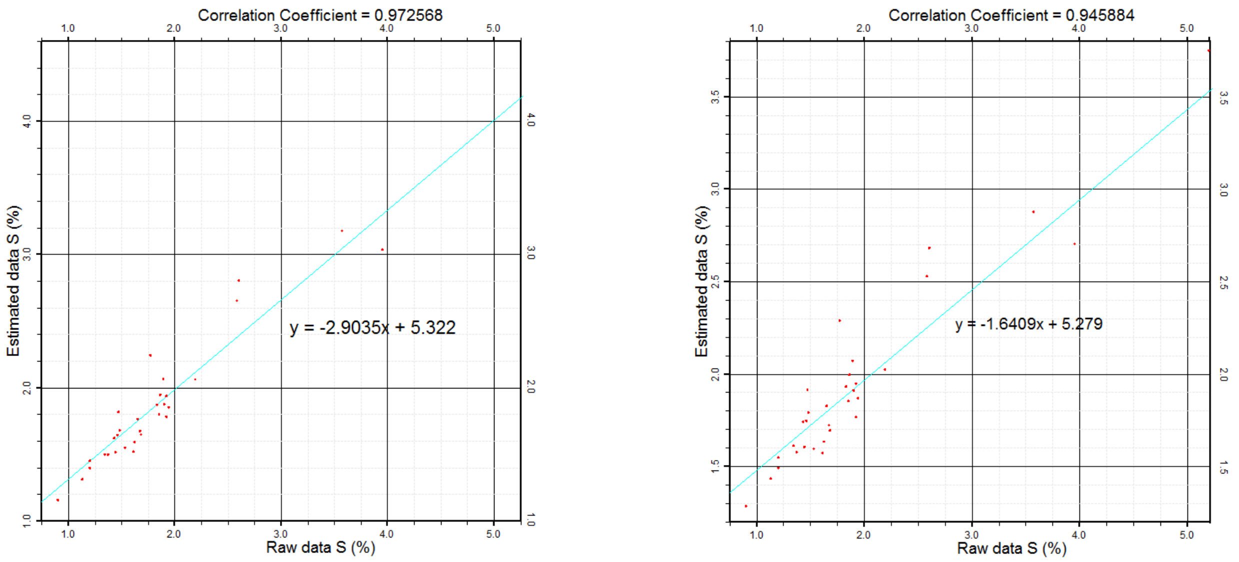
The means for the estimated and raw data were compared for ash and sulfur values. The ash means for the raw data, and the estimated AIDS and OK data were 12.82%, 9.91% and 9.1%, respectively. Moreover, the average values for the raw data, and the estimated AIDS and OK data were equal to 1.968%, 0.987%, and 0.976%, respectively. On the other hand, variances for the ash raw and the estimated data were compared; they were 485.63, 116.9, and 91.3 for the raw, and the estimated AIDS and OK data, respectively. Furthermore, variances for the sulfur raw and estimated data were 3.79, 0.89, and 0.84 for the raw, and the estimated AIDS and OK data, respectively. These parameters are similar but the means of AIDS and variances due to OK are near the raw data.

For validation of the results, the correlation coefficients between the raw and estimated data were calculated and the correlation charts were drawn, as depicted in Figures 7 and 8. The results obtained for this operation indicate that the correlation coefficients are the same, while AIDS is better than OK. On the other hand, the correlation coefficients according to AIDS are higher than OK. This can be interpreted based on the ore deposit type that is a sedimentary deposit. In addition, the jackknife method, as a technique from cross-validation methods, was used. Based on this method, 20% of data was removed and the ash and sulfur distributions were re-estimated by 80% of the data. The correlation coefficient between the removed data and the related voxels were higher than 90%. It shows that the estimation operation is acceptable. Furthermore, this process indicates that AIDS has a higher correlation coefficient than OK.



(a) (b)

Figure 7. Correlation charts between raw and estimated data for ash based on AIDS (a) and OK (b).



(a) (b)

Figure 8. Correlation charts between raw and estimated data for sulfur based on AIDS (a) and OK (b).

5. Conclusions

Selecting a proper method for estimation of ore resources/reserves with an appropriate accuracy is essential in geostatistical modeling. In this research work, the OK and AIDS approaches were carried out and compared in a coal deposit. The geostatistical modeling with both methods based on the ash and sulfur values indicates that AIDS is better than OK. Consequently, the correlation coefficients between the raw and estimated data were higher in the AIDS method. Furthermore, the ash and sulfur means were near their estimated means according to the AIDS technique. Therefore, the AIDS technique has an accuracy higher than the OK method for estimation of the parameters in the East-Parvadeh coal ore deposit.

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مقایسه روش‌های کریجینگ معمولی و عکس مجذور فاصله پیشرفته بر اساس تخمین ذخایر زغال‌سنگ، مطالعه موردی: پروده شرقی، ایران مرکزی

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چکیده:

یافتن روش مناسب تخمین برای منابع / ذخایر معدنی در مهندسی معدن یکی از موارد مهم محسوب می‌شود. هدف از این پژوهش، مقایسه روش‌های کریجینگ معمولی و عکس مجذور فاصله پیشرفته بر اساس ارتباط بین داده‌های خام و برآورد شده در ذخایر زغال‌سنگ پروده شرقی در ایران مرکزی است. واریوگرام و بیضوی ناهمسانگرد برای محاسبه توزیع خاکستر و گوگرد توسط روش‌های مذکور محاسبه شدند. نتایج حاصل از این روش‌ها نشان می‌دهد که ضرایب همبستگی آن‌ها برای داده‌های خام و برآورد شده مشابه هستند. با این وجود، پارامترهای آماری حاصل از روش عکس مجذور فاصله پیشرفته بر اساس روش خاکستر و گوگرد بهتر است، اگرچه واریانس این متغیرها با توجه به روش کریجینگ معمولی کمتر است .نتایج به دست آمده نشان می‌دهد که روش عکس مجذور فاصله پیشرفته نتایج قابل اعتمادتری نسبت به روش کریجینگ معمولی دارد.

کلمات کلیدی: عکس مجذور فاصله پیشرفته، کریجینگ معمولی، زغال‌سنگ، پروده شرقی.