Journal of Advanced Research in Applied Sciences and Engineering Technology 33, Issue 1 (2023) 267-274

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Distance of Drill-Hole Determination based on Global Estimation Variance of Coal Resources Classification

Nur Ali Amri[1,*], Septi Wulandari[1], Tedy Agung Cahyadi[1], Inmarlinianto[2], Satria Abadi[3]

[1] Mining Engineering Department Universitas Pembangunan Nasional "Veteran" Yogyakarta, Indonesia
[2] Department of Mathematical Sciences, Faculty of Science and Technology, Universiti Kebangsaan Malaysia Bangi, Selangor, Malaysia
[3] Faculty of Computing and Meta-Technology, Universiti Pendidikan Sultan Idris, Perak, Malaysia

ARTICLE INFO

Article history:
Received 28 May 2023
Received in revised form 20 September 2023
Accepted 3 October 2023
Available online 19 October 2023

Keywords:
Optimum drill hole spacing; sill variogram; coal; global estimation variance

ABSTRACT

Based on SNI 5015:2019, the estimation of coal resources is based on geological conditions, as well as the distance of information points for each geological condition and resource class. PT. AMNK is a coal mining company and has now started mining. The mines are divided into three blocks, north, middle, and south. Drilling activities have been carried out in the middle block, with 66 drilling points resulting in 4 main seams namely, H seam, I seam, J seam, and K seam. The average drill hole distance is 150 m. This type of coal deposit belongs to the moderate geological group characterized by the presence of a fault in the middle block. Further analysis of optimum drill hole distances is carried out as a basis for the estimation and classification of resources, which in 2024 will be used as an exploration target for the southern block. Analysis of the optimum drill hole distance based on the "relative error" value using the GEV (Global Estimation Variance) method and the size of the sill variogram. Based on the analysis of the K seam, the optimum borehole distances were 385 m, 750 m, and 1750 m, measured, indicated, and inferred categories, respectively.

1. Introduction

The mining materials, metal minerals (gold, nickel, silver, etc.), uranium, coal, and so on, are commodities that are mostly located in remote areas. Most of them exist in the depths of tens to hundreds of meters below the surface of the ground. Therefore, to find out the distribution and calculate the volume, we need the right method.

Mining business, as Regulation of the Minister of Energy and Mineral Resources Republic of Indonesia Number 26 of 2018 is the activities for the exploitation of minerals or coal. The exploitation includes general investigation, exploration, feasibility study, construction, mining, processing and/or refining, transportation and sales, and post-mining. Exploration, exploitation, and processing, are several stages that make the mining industry a high-cost business.

* *Corresponding author.*
E-mail address: amri.upn.jogya@gmail.com

https://doi.org/10.37934/araset.33.1.267274

Exploration is an activity to obtain data for resource volume calculations (including reserves). This data obtains detailed information in many mines obtained from drilling results. The drilled material is then crushed and chemically tested to obtain information on its content, especially the grade used as a basis for issuing the classification of a commodity.

The resource classification in this study is coal commodity, whose sample data is obtained from drilling. The distance between drill hole samples, as per SNI 5015:2019 [1], may be extended if technically supported by scientific studies, in this case, geostatistical analysis. The analytical method for determining drill hole spacing, Drill Hole Spacing Analysis (DHSA), as was used in this study [2].

Bertoli *et al.,* [3] used Global Estimation Variance (GEV) on DHSA events. In his research, this method was compared with the Australian Coal Guidelines classification and the estimation of hole distance analysis based on a geostatistical approach. This approach leads to a level of certainty commensurate with the complexity of geology [3].

2. Materials and Method

2.1 Data

The sample data in this study were 66 drilling points in one of the middle seams of the four existing seams, namely, H-seam H, I-seam, J-seam J, and K-seam, owned by PT. Atha Marth Naha Kramo, where the average drill hole distance is 150 m.

The drilling depth is quite varied, where the average is 90.67 m, with the most bottomless drill hole, 134.32 m, and the shallowest 36, 01 m. This area is a moderate geological group, one characterized by the finding of fault indications. Map of drill hole distribution coordinates as shown in Figure 1.

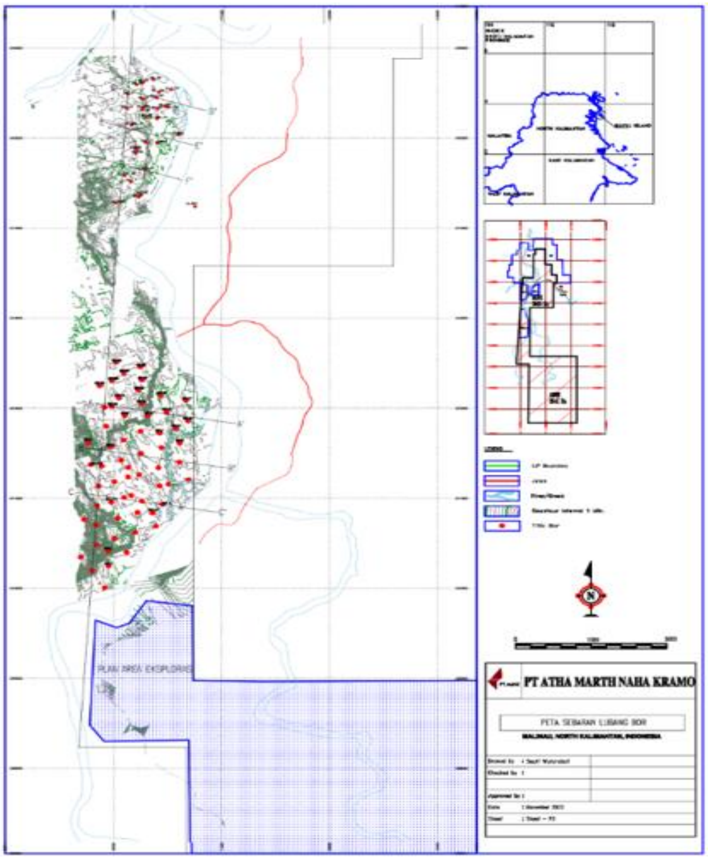

Fig. 1. Drill hole distribution map

2.2 Statistics

Analysis of the average statistical parameters, minimum, maximum, variance, standard deviation, and coefficient of variance (CoV) of the samples was carried out on the thickness, ash content, and calorific value of the coal as in Table1. K-Seam, with a thickness of 6.95 m, has an average ash content of 2.22% and a coefficient of variation (CoV). This measure describes the relative variability to an average grade of 0.10.

Table 1
Statistical analysis result for the K-Seam

Variable	Min	Max	Count	Mean	Std. Dev.	CoV	Skewness
Thickness	4.26	6.69	66	5.29	0.54	0.10	0.30
Ash	1.90	2.80	27	2.22	0.23	0.10	1.08
Total Sulphur	0.07	0.19	27	0.11	0.02	0.18	1.24
CV	5220	5969	27	5593	171.04	0.03	-0.22

Dominy *et al.,* and Fytas *et al.,* said that the data distribution is still in the normal category for CoV, which is less than 1.5 [4,5]. As in Table 1 column 7, all CoV values are below 1.5. Therefore, neither top cut nor downgrade is necessary, and the resulting variogram values are acceptable [4,5]. Cambardella index (CI) as expressed in Eq. (1) is a parameter that describes strong spatial dependencies and slight erratic variance if CI < 0.25; 0.25 < CI < 0.75 means moderate spatial dependency; whereas for CI > 0.75, the spatial distribution is random [6]. The other three variables, thickness, total sulfur, and CV (calorific value), as shown in Table 1, are also normally distributed. The distribution of the data is good enough that it does not need to be verified.

$$\mathrm{CI}(\%) = \left(\frac{\mathrm{C}_0}{\mathrm{C}_0+\mathrm{C}_1}\right) \times 100 \tag{1}$$

with C_0 is a nugget effect and (C_0+C_1) is a sill.

2.3 Variogram

Geostatistics is a statistical method for spatial phenomena whose dependencies between data are measured using a variogram. The parameters resulting from the variogram fitting, namely nuggets, sills, and ranges, then become the basis for kriging for estimating areas where data has not yet been obtained [7]. The variogram shows the variability between two data separated by distance in an area [8]. Variograms are applied to see the variability between two data separated by distance in an area [8]. The variogram is a vector relationship $h = s_i - s_j$ or a distance relationship with a direction angle $h = (L, \theta)$, where L is the lag. The experimental variogram formula as shown in Ref. [9] is

$$\gamma(h) = \frac{1}{2|N(h)|}\sum_{N(h)}\left[Z(\mathrm{s}_i) - Z(\mathrm{s}_j)\right]^2 \tag{2}$$

where h represents the distance between samples, si as the price (data) at point *i*, and s_j is data at point *h* from point *i*.

Variogram fittings were run on all K seam coal quality data with azimuth direction *N* 0^0E, dip 0^0 and tolerance 90^0 (omni directional) using spherical model.

$$\gamma(\text{h}) = \begin{cases} 0, & \text{h=0} \\ C_0 + C_1\left(\frac{3}{2}\left(\frac{|\text{h}|}{a}\right) - \frac{1}{2}\left(\frac{|\text{h}|}{a}\right)^3\right), & 0<\text{h}\leq a \\ C_0 + C_1, & |\text{h}|>0. \end{cases} \quad (3)$$

Block ordinary kriging for the mean estimated by Ref. [10] is

$$\bar{\hat{\text{Z}}}(v) = \frac{1}{n(\mathbf{s}_{0i})}\sum_{i\in\mathbf{s}_{0i}} \text{Z}(\mathbf{s}_{0i}), \ \mathbf{s}_{0i} \in v. \quad (4)$$

$\text{Z}(\mathbf{s}_{0i})$, ($i$=1, …, n) are the estimated points in block v where

$$\text{Z}(\mathbf{s}_{0i}) = \sum_{i=1}^{n} w_i \text{Z}(\mathbf{s}_i), \ \mathbf{s}_i \in V. \quad (5)$$

The maximum distance parameter used as a practical is 3000 m with the lag distance adjusting to the distribution of the data. The average drilling distance is 150 m. SGemS software data processing used here. The results of the variogram fitting, here Eq. (2) fitted by Eq. (3), as in Table 2 are for each parameter to be a determinant of the success of the spatial analysis.

Table 2
Variogram parameters of the seam k based on spherical fittings

Variable	Nugget variance (C_0)	Sill (C)	Range (a)	Coefficient of variation (CoV)	Cambardella index (CI)
Thickness	0,100	0,270	1275	0.10	0.270
Ash	0,040	0,019	600	0.10	0.678
Total sulphur (TS)	0,0004	0,00027	825	0.22	0.597
CV	0,0000	32200	450	0.03	0

2.4 Borehole Distance Optimization

DHSA drill hole spacing optimized based on Bertoli *et al.,* [3] Determining the optimum drill hole spacing for coal deposits is then compared to the SNI 5015: 2019 guidelines. The drill hole distance will be optimal if we take it from the smallest optimal distance obtained from each approach which we will later use as the basis for further exploration plans.

2.5 Bertoli Criteria

GEV is a resource classification method based on relative error values introduced by Bertoli *et al.,* [3]. The Relative Error value is then plotted onto a graph to determine the optimum drill hole distance. The steps carried out by Ref. [11] are to find the value of the extension/estimated variance (σ_k^2) point to block for the spherical model where the nugget variance value, 0 and sill value, 1 by plotting on the spherical model (Eq. (3)) diagram as shown in Ref. [12]. The calculation of the variance of the point estimate of the plane, $\sigma_e^2(r)$, is carried out by adjusting the nugget variance and sill of each parameter where

$$\sigma_{\text{e}}^2(\text{r}) = \text{C0} + (\text{C} * \sigma_{\text{k}}^2) \quad (6)$$

The global estimated variance value $\sigma_e^2(R)$ from dividing the estimated variance value over the number of blocks (*N*) is

$$\sigma_e^2(R) = \sigma_e^2(r)/N \quad (7)$$

A calculation of the relative error value based on

$$\text{Relative Error} = \pm 1.96\ \sigma_e \times 100\%/\text{mean} \quad (8)$$

3. Results and Discussion

3.1 Optimization of Borehole Spacing

Based on Table 2 column six, the Cambardella index (Eq. (1)) values for the three variables are thickness, ash, and total sulphur are in the interval of 0.25 – 0.75, which means that the spatial dependencies are in the moderate category [13]. However, as in column five, all variables produce fewer CoV values than 0.5. There is no need for a top cut or downgrade, and the resulting variogram is acceptable.

Bertoli based on the GEV method as a whole take into the account of grades variation at close range from the value of the nugget effect, the spatial homogeneity and continuity indicated by the range, and the size of the study area. This approach also considers the population and the variation of the grade data represented by the mean grade and the variance by which the sill values approximate the variance.

The GEV calculation starts from the mean value based on the statistical analysis results for each parameter. The h and l values are the distances between the drill holes added up in multiples of 150 based on the average value of the drill hole distances in the study area assuming *h* and l are of the same area. The difference between the maximum and minimum coordinates is divided by the drill hole distance, and the value of *N* is the product of the maximum and minimum values multiplied. The extension/estimation variant is the result of reading the drill hole distance/range (*a*) on the diagram (nomogram) for the spherical model [12].

A calculation of the variance of the point estimate over fields ($\sigma_e^2(R)$) and the global estimate variance is the ratio between the value of the point estimate variance against the number of fields and the amount of *N* data. The relative error value is obtained by multiplying the confidence level with a constant of 1.96 and the standard deviation divided by the mean. This value is the relative error for every multiple of the drill hole distance of 150 meters. Making a drill hole distance chart is done by reading the value of the drill hole distance and the relative error value of the coal quality and thickness variables. The line drawing for drill hole spacing is based on Bertoli *et al.,* [3], is to read the distance to the relative error value when it reaches a value of 10% (measured resource category), a value of 20% for indicated resources, and 50% for the inferred resource category (Figure 2).

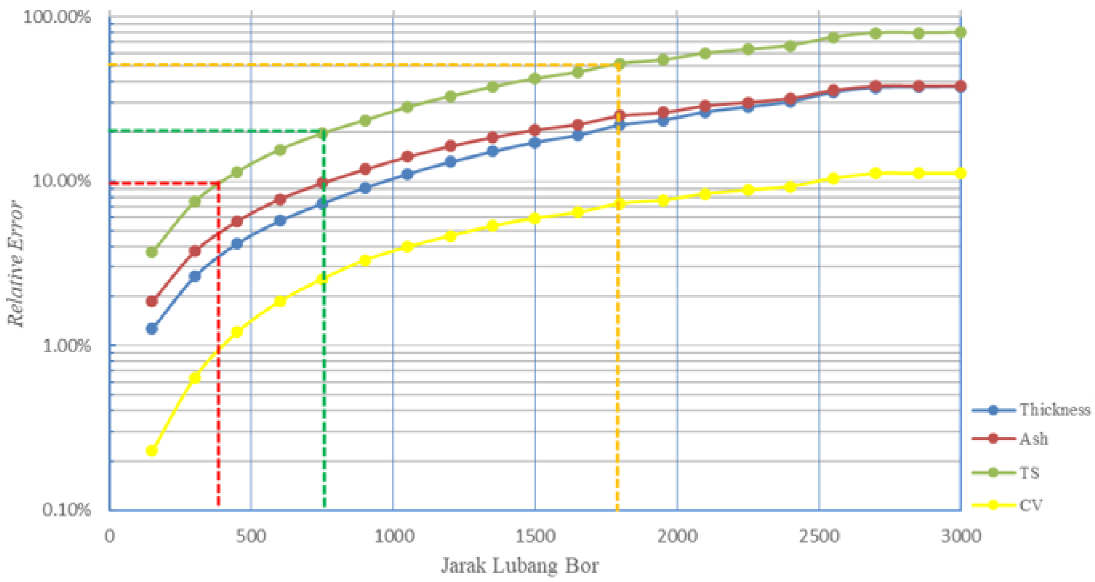

Fig. 2. Determination of the optimum drill hole spacing based on the relative error of *Bertoli et al.,* [3] on K-Seam

Based on the stages of calculations made and through reading an analytical chart, it is possible to obtain the optimum drill hole distances for the measured, indicated, and inferred resources on K-seam, respectively, 385 m, 750 m, and 1750 m.

3.2 Optimum Borehole Spacing

The optimum borehole spacing for coal deposits in the study area was determined based on the Bertoli *et al.,* [3] criteria used the relative error value of the GEV method. The results obtained for the calculation of drill hole spacing analysis are shown in Table 3. Using the GEV approach on seam K for the measured, indicated, and inferred categories are 385 m, 750 m, and 1750 m, respectively. The results of this approach are compared with the SNI 5015:2019 guidelines. A comparison of the results of the optimization approach to drill hole spacing with SNI 5015:2019 can be seen in Table 3.

The determination of drill hole spacing based on SNI 5015: 2019 guidelines is also based on geological complexity with several sedimentation parameters, tectonics, and variations in coal quality. The research area is included in a group of moderate geological conditions characterized by quite varied thicknesses, the existence of branching for several coal seams, with faults from the tectonic aspect, and varying quality.

Table 3
Comparison of the results of the optimization approach to the distance of the K-Seam drill holes based on SNI 5015:2019

No	Borehole spacing optimization approach	Optimum distance		
		Measured	Indicated	Inferred
1	Global estimation variance (measured 10%, indicated 20%, inferred 50%)	385	750	1750
2	SNI 5015:2019 (geological moderate)	250	500	1000

The GEV approach considers the population and variation of coal quality data based on sill values (C_0+C) as values that are close to the variance. The GEV method also uses the nugget effect (C_0), meaning variations in levels at close range are also considered. The optimum drill hole distance is 385 m for the measured category, 750 m for the indicated category, and 1750 m for the inferred category. These results are expected to be used to determine the distance of drill holes for further exploration activities in the broader area.

The distribution of 75 m × 75 m block contour of kriging and kriging variance estimation is as shown in Figure 3.

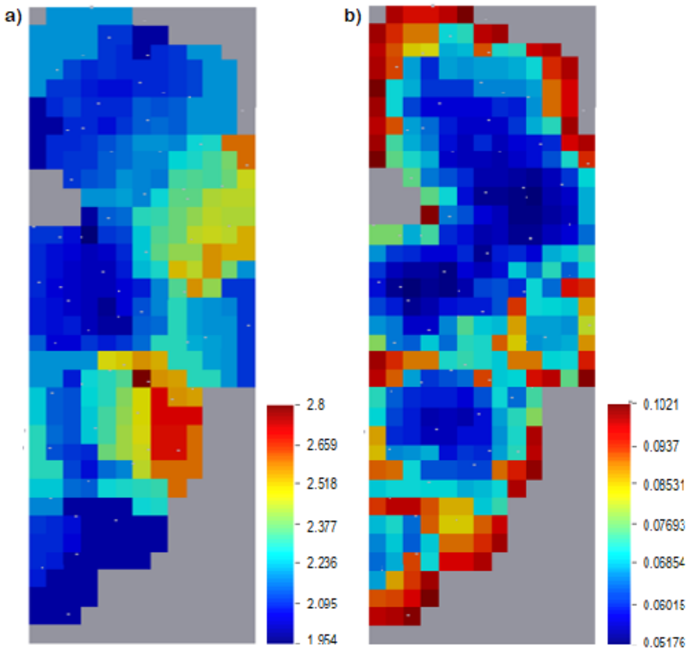

Fig. 3. Contour of 75 M × 75 M Block a) Kriging estimation and b) variance Kriging estimation for Ash of K-Seam

4. Conclusions and Recommendations

An optimization of borehole spacing on Seam K through the GEV approach where the resulting parameters are based on the criteria of Bertoli, 385 m, 750 m, and 1750 m respectively, for the category of measured, indicated, and inferred resources. Optimum drill hole spacing based on this approach refers to drill hole spacing simulations for regions globally to represent a wider follow-up exploration area in the study area.

The author's hope, as well as a suggestion, is that, in the future, method development can be carried out to obtain more accurate calculations related to determining the optimum drill hole distance so that mining exploration costs can be reduced.

Acknowledgement
Thanks to the management of PT. Atha Marth Naha Kramo for the permission and data acquisition, and to UPN "Veteran" Yogyakarta, especially the Department of Mining Engineering for the facilities and opportunities.

References

[1] Indonesia, Standar Nasional. "Pedoman pelaporan hasil eksplorasi, sumber daya, dan cadangan batubara." (2019).

[2] Martínez-Vargas, Adrian. "Optimizing grade-control drillhole spacing with conditional simulation." *Minería y Geología* 33, no. 1 (2017): 1-12.

[3] Bertoli, Olivier, Andrew Paul, Zach Casley, and Doug Dunn. "Geostatistical drillhole spacing analysis for coal resource classification in the Bowen Basin, Queensland." *International Journal of Coal Geology* 112 (2013): 107-113. https://doi.org/10.1016/j.coal.2012.12.010

[4] Dominy, Simon C., Alwyn E. Annels, G. Simon Camm, Paul Wheeler, and Suzanne P. Barr. "Geology in the resource and reserve estimation of narrow vein deposits." *Exploration and Mining Geology* 4, no. 6 (1997): 317-333.

[5] Fytas, K., N-E. Chaouai, and M. Lavigne. "Gold deposits estimation using indicator kriging." *CIM bulletin* 83, no. 934 (1990): 77-83.

[6] Santesteban, L. G., S. Guillaume, J. B. Royo, and Bruno Tisseyre. "Are precision agriculture tools and methods relevant at the whole-vineyard scale?." *Precision Agriculture* 14 (2013): 2-17. https://doi.org/10.1007/s11119-012-9268-3

[7] Schabenberger, Oliver, and Carol A. Gotway. *Statistical methods for spatial data analysis*. CRC press, 2017. https://doi.org/10.1201/9781315275086

[8] Sianturi, Raymond Kosher, Mohamad Nur Heriawan, and Syafrizal Syafrizal. "Analisis Spasi Lubang Bor Untuk Mengevaluasi Sumberdaya Timah Aluvial Dan Mineral Ikutannya Di Pulau Bangka Dengan Global Estimation Variance." *Riset Geologi dan Pertambangan-Geology and Mining Research* 30, no. 2 (2020): 153-169. https://doi.org/10.14203/risetgeotam2020.v30.1115

[9] Matheron, Georges. "Principles of geostatistics." *Economic geology* 58, no. 8 (1963): 1246-1266. https://doi.org/10.2113/gsecongeo.58.8.1246

[10] Sarma, Dhavala Dattatreya. *Geostatistics with applications in earth sciences*. Springer Science & Business Media, 2010. https://doi.org/10.1007/978-1-4020-9380-7

[11] Cornah, Alastair, John Vann, and Ian Driver. "Comparison of three geostatistical approaches to quantify the impact of drill spacing on resource confidence for a coal seam (with a case example from Moranbah North, Queensland, Australia)." *International journal of coal geology* 112 (2013): 114-124. https://doi.org/10.1016/j.coal.2012.11.006

[12] Wellmer, Friedrich-Wilhelm. *Statistical evaluations in exploration for mineral deposits*. Springer Science & Business Media, 2012.

[13] Cambardella, Cynthia A., T. B. Moorman, J. M. Novak, T. B. Parkin, D. L. Karlen, R. F. Turco, and A. E. Konopka. "Field-scale variability of soil properties in central Iowa soils." *Soil science society of America journal* 58, no. 5 (1994): 1501-1511. https://doi.org/10.2136/sssaj1994.03615995005800050033x