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Research paper

Optimizing of Drill Hole Spacing for Coal Resources Classification in Kelay Block 3 Area, Labanan Formation, Berau Regency, East Kalimantan

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Abstract

Optimizing of drill hole spacing for coal resource classification is a method for optimizing and evaluating coal resources in a seam within a coal mining area. The Kelay Block 3 area is included in the concession of PT Berau Coal, Berau Regency, East Kalimantan. The main coal-bearing formation is the Labanan Formation. The Labanan Formation is known to have fairly thick and low-quality coal seams. Exploration drilling has been conducted at 69 drilling locations, consisting of 34 core drilling locations and 35 open-hole drilling locations. The coal resource classification in the study area falls into the moderate geological condition category according to SNI 5015:2019. This research was conducted to analyze the optimal borehole spacing in the Labanan Formation for coal resource evaluation and classification in the study area using the global estimation variance (GEV) approach. The results obtained from optimizing borehole spacing in the study area were taken at a spacing of 350 m for the measured category, 600 m for the indicated category, and 1200 m for the inferred category, based on the thickness variable. This is because the global estimation variance (GEV) method considers population and variation, which are values that approximate variance thru GEV analysis. Optimizing borehole spacing using the global estimation variance (GEV) method showed wider and more optimal results than the provisions of SNI 5015:2019 under the same geological conditions.

Keywords: *Labanan Formation, Global estimation variance, Optimizing drill hole spacing*

1. Introduction

The Kelay Block 3 area in Berau Regency, East Kalimantan, is regionally geologically part of the Berau Sub-Basin, which is part of the Tarakan Basin. The main coal-bearing formations in the Berau Sub-Basin are the Labanan Formation and the Lati Formation. The study area is included in the Labanan Formation (tmpl), which can be seen in Figure 1. The Labanan Formation (tmpl) is composed of conglomerate sandstone, shale, coal, and at the top, there is an Alluvial Deposit (Qa) consisting of gray to black mud, sand, gravel, pebbles, and peat [1]. The Labanan Formation is known to have fairly thick and low-quality coal seams [2].

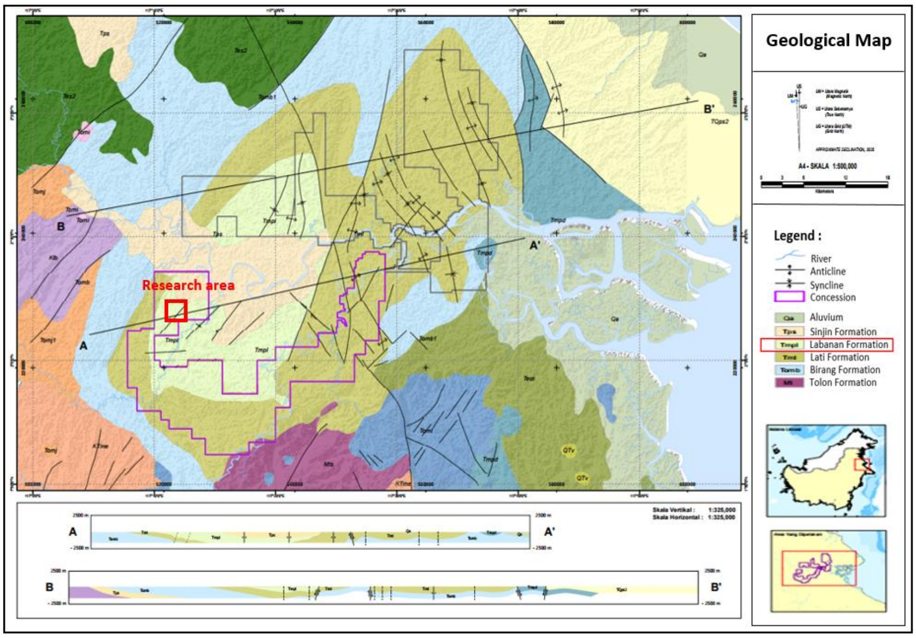

Fig 1: Regional geological map of the Tanjung Redeb sheet, East Kalimantan (Situmorang and Burhan, 1995).

Exploration drilling activities in the research area have been completed with an average borehole spacing of 250 m. The type of coal deposit in the research area, based on SNI 5015:2019, falls into the moderate geological group. PT Berau Coal plans further exploration in the Kelay Block 3 area, necessitating a drill hole spacing analysis (DHSA) to ensure accurate resource estimation and classification. The current evaluation of coal resources is based on Indonesian National Standard 5015:2019, with the level of geological confidence quantitatively determined by borehole spacing and the complexity of moderate geological conditions [3]. The level of geological confidence is influenced by several factors, namely the quality, quantity, and distribution of drilling points [4]. There are 2 (two) methods for analyzing borehole spacing [5], namely (a) Drill Hole Spacing Analysis (DHSA) and (b) Drill hole spacing optimization with conditional simulation [6]. Borehole spacing analysis, also known as drill hole spacings analysis (DHSA), is a method used to evaluate the level of resource confidence using a geostatistical approach for coal deposits. DHSA provides the global estimation variance (GEV) value [7]. Drill hole spacing analysis (DHSA) is considered more objective and yields results that closely reflect the complexity of the geological conditions in the study area [8]. This research was conducted to analyze the optimum borehole spacing in the Labanan Formation for coal resource evaluation and classification in the study area using the global estimation variance (GEV) approach.

2. Method

The research was conducted in several systematic stages, resulting in outcomes that align with the research objectives. The research stages can be seen in Figure 2.

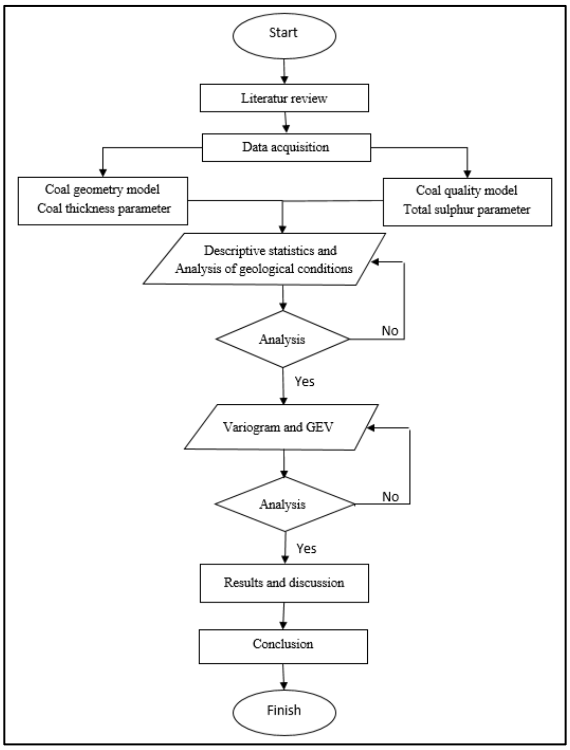

Fig 2: Research flowchart

2.1 Literature review

The initial stage involved collecting and reviewing literature on the regional geology of the Berau Sub-Basin, which is part of the Tarakan Basin, the stratigraphy and coal quality of the Labanan Formation, and the theory of geostatistical analysis.

2.2 Data acquisition

The data used in this study is secondary data consisting of quality data and geometric data from the results of coal exploration drilling conducted by the company at the Kelay Block 3 mine in the Labanan Formation, which was then used for geometric modeling and quality modeling to create a coal geological model. Coal quality data is represented by the variable total sulfur (% adb), and geometric data is represented by coal seam thickness in meters. The total number of exploration drilling data points conducted in the study area is 69, consisting of core drilling and open-hole drilling with a fairly regular pattern (as shown in Figure 2), which were used for the geometry variable. The quality variable had 34 core drilling data points. Core drilling was conducted between open-hole points after the coal geometry distribution pattern was known, followed by coal sample collection to determine the initial characteristics of the quality distribution in the study area as part of the operational strategy for the exploration activities. Data from wells that meet the criteria are then subjected to descriptive or basic statistical analysis and outlier determination.

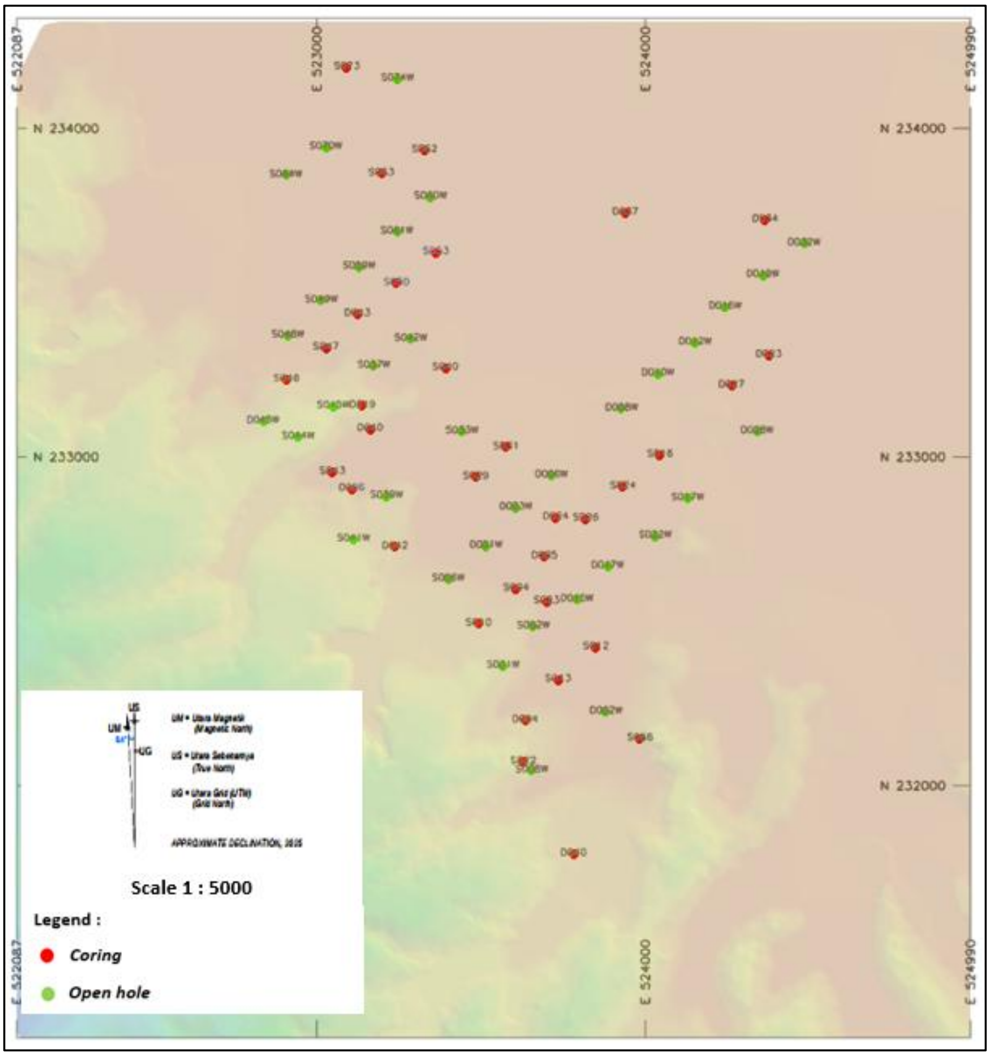

Fig 3: Distribution of drilling points at the Kelay Block 3 mine

2.3 Descriptive statistics

Statistical analysis was conducted to determine the values of each variable used in this study, which is descriptive statistical analysis. Descriptive statistics in the research area can be seen in Table 1.

Table 1: Statistical description of each variable at the Kelay Block 3 area

Variabel	Count	Mean	Median	Std Dev	CoV	Min	Max
Coal geometry:							
Thickness (m)	69	10.68	11.24	4.91	0.46	0.79	20.74
Coal quality:							
Total Sulphur (Adb)	34	0.10	0.11	0.04	0.34	0.03	0.20

The data variation for the variables thickness and total sulfur in Table 1 has a uniform and normally distributed spread based on the coefficient of variation (CoV) value. If the data shows a coefficient of variation (CoV) below 1.5, the data variation is relatively uniform and well-distributed. If the coefficient of variation (CoV) reaches 1.5 or more, it indicates the presence of data outliers that can affect variogram analysis [10]. The presence of outliers will result in high deviations in the sample population [9][10].

2.4 2.4. Analysis of geological conditions

SNI 5015:2019 divides the complexity of geological conditions into three categories: simple, moderate, and complex. The competent person (CP) descriptively assesses these geological conditions based on sedimentation aspects, tectonic aspects, and quality variations. In this study, geological conditions were assessed based on the SNI 5015:2019 categories. The results of the geological condition assessment can be seen in Table 2, while Table 3 details the required borehole spacing for each coal resource category based on geological complexity.

Table 2: Analysis of geological conditions in the research area (SNI 5015:2019)

Parameter	Geological conditions		
	Simple	Moderate	Complex
Sedimentary Aspects			
1. Thickness variations	Low variation	Moderate variation	High variation
2. Continuity	Thousands of meters	Hundreds of meters	Tens of meters
3. Spliting	Almost none	Few splitting	Many splitting
Tectonic aspects			
1. Faults	None	Rarely	Tightly
2. Folds	Gentle	Moderate folded	Strong folded
3. Intrusion	None	Influenced	High influenced
4. Dip	Gentle	Moderate	Steep
Qualities variation	Low variation	Moderate variation	High variation

Table 3 : Coal resource categories based on drill hole spacing (SNI 5015: 2019).

Geological conditions	Categories		
	Inferred	Indicated	Measured
Simple	1000 < x ≤ 1500	500 < x ≤ 1000	x ≤ 500
Moderate	500 < x ≤ 1000	250 < x ≤ 500	x ≤ 250
Complex	2500 < x ≤ 500	100 < x ≤ 250	x ≤ 100

The determination of geological condition parameters was obtained from local geological maps, coal seam structure cross-sections, and coal quality statistical data. From Table 2, based on the descriptive assessment by a competent person (CP), the geological conditions at the research location are generally moderate.

2.5 2.5. Variogram analysis

Variogram analysis is an essential step in geostatistics used to describe the variation of a parameter as a function of spatial separation. It is based on the principle that two points located close to each other in space are more likely to have similar parameter values than two points that are far apart. Variograms can be classified into two types: omnidirectional, where the search direction is unrestricted, and directional, where the search direction is limited to specific spatial orientations [11]. The experimental variogram is calculated by averaging the squared differences in parameter values between two samples separated by distance (h). Mathematically, the variogram can be expressed as [12]:

$$\gamma(\mathrm{h}) = \frac{\sum_{i=1}^{n}[Z(Xi)-Z(Xi+h)]^2}{2\mathrm{N}(\mathrm{h})} \quad (1)$$

Where :
γ(h) = experimental variogram,
$Z(Xi)$ = value at location (Xi),
$Z(Xi + h)$ = value at location (Xi) separated by space (h).

Construction of the Experimental Variogram

1. Lag (h) and lag class definition

The lag distance h represents the spatial separation between sample pairs. In practice, the spatial domain is divided into several lag classes, each covering a specific range of distances (for example, every 20–50 meters). The lag interval must balance spatial resolution and statistical stability. If the lag interval is too small, the number of sample pairs may be too low, producing noisy or unstable variogram values. If it is too large, important spatial variations may be lost.

2. Number of sample pairs (N(h))

For each lag class, the number of sample pairs whose spatial separation falls within that interval is counted. A larger number of pairs produces more reliable variogram values. Variogram points with very few pairs are often unstable and must be interpreted with caution or smoothed during model fitting.

3. Evaluation of anisotropy

To determine whether spatial correlation depends on direction, variograms are calculated along multiple orientations (for example, 0°, 45°, 90°, or 135°). If variograms in different directions display similar ranges and variances, the dataset is considered isotropic and an omnidirectional variogram is appropriate. If strong directional differences are observed, geometric or zonal anisotropy must be incorporated into the model.

The experimental variogram was constructed and fitted using the geostatistical modeling software SGeMS. In this study, an omnidirectional variogram with a search direction of N 0° E and an angular tolerance of 90° was selected, allowing the pairing of sample values in all directions. A spherical model was chosen for variogram fitting, as it represents spatial continuity that increases rapidly at short distances and stabilizes beyond a defined correlation limit. The fitted variogram model produces three primary geostatistical parameters:

a. Nugget (C_0): represents variability at very small spatial scales, including measurement error and micro-scale heterogeneity.
b. Range (a): the maximum distance within which samples remain spatially correlated. Samples separated by distances greater than the range are assumed independent.

c. Sill ($C = C_0 + C_1$): the total variance at which the variogram reaches a stable plateau.
The variogram fitting results show low nugget and sill values, approaching zero, indicating minimal micro-scale variability and strong spatial continuity. The range values are relatively large, implying a wide zone of influence and high spatial correlation, effectively representing the dataset. The resulting geostatistical parameters from the spherical variogram model are shown in Table 4.

Table 4: Spatial Statistical Test Parameters using the Spherical Model at Kelay Block 3 area

Variabel	Nugget (C_0)	Sill (C)	Range (a)	CoV
Thickness (m)	0.370	21.000	435	0.46
Total Sulphur (Adb)	0.0001	0.0014	300	0.36

2.6 Relative error calculation using Global Estimation Variance (GEV)

The block model used for Global Estimation Variance (GEV) calculations was constructed by subdividing the study area into uniform volumetric cells (blocks). The block dimensions were determined based on drillhole spacing and geological continuity to preserve local variability while avoiding excessive smoothing. In this study, the block size was set at approximately half of the average borehole spacing, ensuring that each block adequately represented the spatial distribution of the variables under analysis. This approach allows each block estimate to be statistically comparable and prevents estimation bias resulting from disproportionate block sizes. The GEV method evaluates the spatial uncertainty of the modeled parameter through the variance of estimation. The calculation begins by applying a normalized spherical variogram with a nugget variance (C0) of 0 and a sill value (C) of 1. This normalization isolates spatial continuity as the sole driver of uncertainty, preventing the influence of measurement noise and scale-dependent variance. The estimation variance for a given block extension distance (r) is expressed as:

$$\sigma_E^2(r) = C0 + (C0 * \sigma^2) \quad (2)$$

where $\sigma_E^2(r)$ is the estimation variance, C_0 represents the nugget effect, and σ^2 is the standardized variance derived from the variogram model. Under a spherical structure with $C_0 = 0$, this simplifies to a variance controlled solely by the spatial structure of the data, reflecting the strength of correlation between samples across distance.
The resulting estimation variance for all modeled blocks is then aggregated to compute the global estimation variance. If N is the total number of blocks in the model domain, the normalized variance is defined as:

$$\sigma_E^2(R) = \sigma_E^2(\gamma) / \mathrm{N} \quad (3)$$

This step transforms local variance into deposit-scale uncertainty by averaging across the total number of blocks. A larger number of blocks reduces the global variance value, indicating stronger confidence in the continuity of the estimated parameter across the resource area. The relative error is subsequently obtained using the standard deviation of the global variance and expressed as a percentage relative to the mean of the modeled parameter:

$$\textit{Relative Error} = \pm 1.96\, \sigma_E \,.\, 100\% / \textit{mean} \quad (4)$$

The factor 1.96 represents the 95% confidence interval under a normal distribution assumption, ensuring the error tolerance reflects statistically meaningful uncertainty. The denominator (mean) corresponds to the average estimated value of the modeled variable (e.g., ore grade, thickness), allowing the relative error to be expressed as a proportion of the deposit characteristics rather than as an absolute magnitude.
In practical terms, this procedure allows resource confidence classification to be performed based on relative error thresholds. Referring to the criteria in Souza et al. (2010) and JORC (2012), a relative error value below 10% corresponds to measured resources, 10–20% corresponds to indicated resources, while values exceeding 20% are categorized as inferred [7][14]. Table 5 summarizes the classification threshold.

Table 5: Classification of resources based on relative error (Souza et al., 2010; JORC, 2012)

Resources Classification	Maximal Extrapolation	Maximal Spacing	Error Tolerance
Measured	500	+ 1 Km < 500 m	0 - 10 %
Indicated	1000	+ 2 Km < 1 Km	10 % - 20 %
Inferred	2000	+ KM4	> 20 %

This expanded explanation provides methodological transparency regarding (1) how the block model was defined and its spatial scale, (2) how the normalized spherical model was applied to compute estimation variance, and (3) how the relative error was derived and interpreted in accordance with established resource classification frameworks.

3. Result and Discussion

3.1 Coal geometry modelling

The geometric modeling of coal distribution in the study area, based on the results of exploratory drilling activities, is oriented Northwest-Southeast, ranging from N 330^0 E, with a layer dip angle between 8^0 and 12^0 degrees. The coal seam thickness varies with some branching, and the seam extends continuously for hundreds of meters. The coal geometry modeling and cross-sections at the Kelay Block 3 mine in the Labanan Formation are shown in Figure 4.

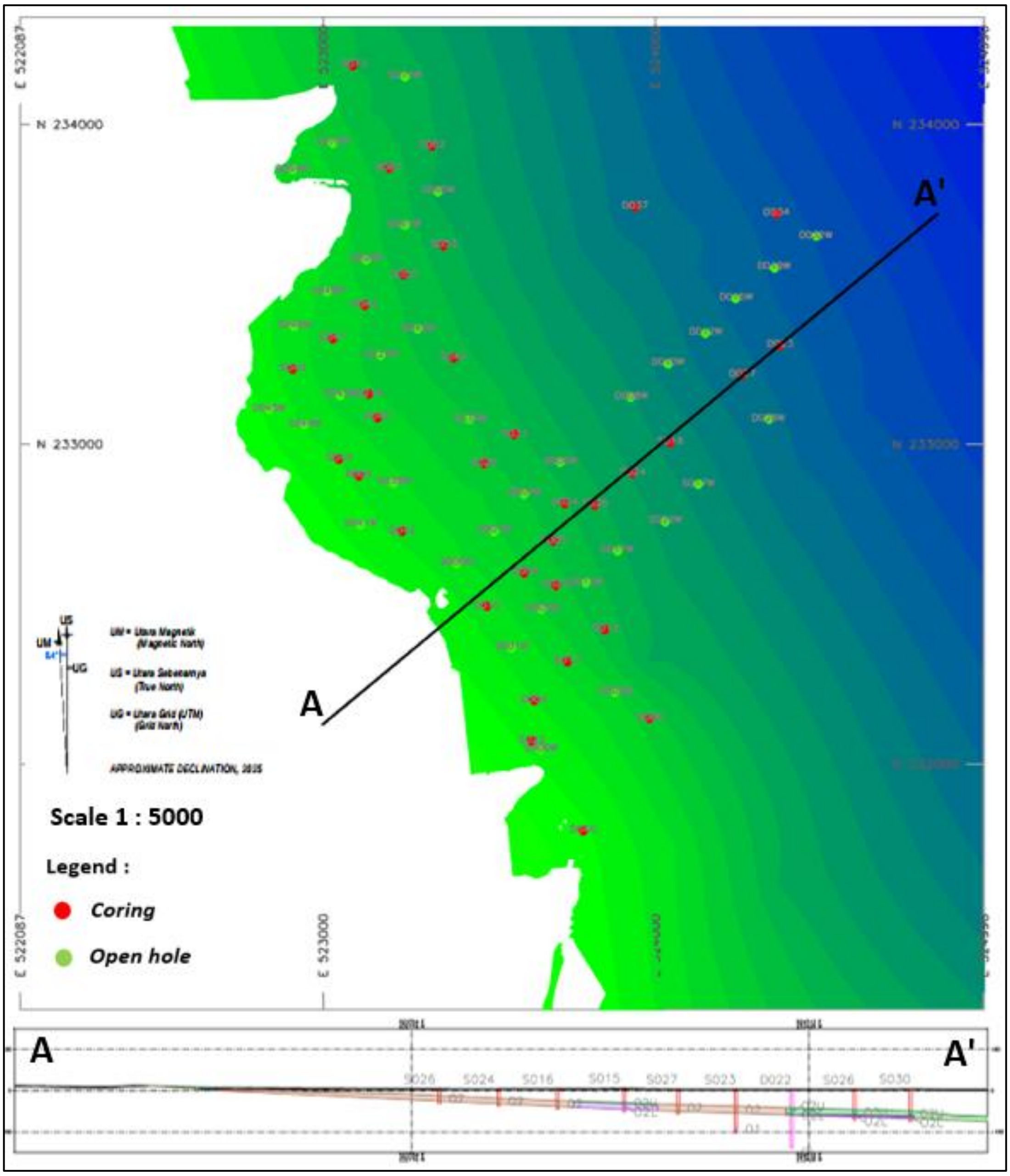

Fig 4: Geometric modeling and coal seam cross-section at the Kelay Block 3 area

3.2 Global Estimation Variance (GEV)

The results of the relative error calculation using the global estimation variance (GEV) for DHSA show relative error values for the borehole spacing scenarios for the parameters of thickness and total sulfur. The relative error values calculated for each variable can determine the borehole spacing limit, so each variable has a different optimal borehole spacing value, which can be seen in Table 6 and Table 7. To see the optimal borehole spacing, the relative error limits for each resource category were used, where the 10% relative error limit is the measured category, the 20% relative error limit is the indicated category, and the 50% relative error limit is the inferred category.

Table 6: Calculation of relative error % using GEV in the thickness parameter.

Global estimation variance															
Coal seam thickness (m)															
Mean	**h**	**l**	**_X**	**_Y**	**N**	**a**	**C_0**	**C**	**h/a**	**l/a**	**Varians**	**σ^2E (r)**	**σ^2E (R)**	**σE (R)**	**% Relative Error**
10.65	50	50	32.938	47.875	1576.88	435	0.37	21.00	0.115	0.115	0.042	1.252	0.001	0.028	0.519
10.65	100	100	16.469	23.938	394.22	435	0.37	21.00	0.230	0.230	0.080	2.050	0.005	0.072	1.327
10.65	150	150	10.979	15.958	175.21	435	0.37	21.00	0.345	0.345	0.130	3.100	0.018	0.133	2.448
10.65	200	200	8.234	11.969	98.56	435	0.37	21.00	0.460	0.460	0.185	4.255	0.043	0.208	3.825
10.65	250	250	6.588	9.575	63.08	435	0.37	21.00	0.575	0.575	0.220	4.990	0.079	0.281	5.177
10.65	300	300	5.490	7.979	43.80	435	0.37	21.00	0.690	0.690	0.275	6.145	0.140	0.375	6.894
10.65	350	350	4.705	6.839	32.18	435	0.37	21.00	0.805	0.805	0.320	7.090	0.220	0.469	8.640
10.65	400	400	4.117	5.984	24.64	435	0.37	21.00	0.920	0.920	0.375	8.245	0.335	0.578	10.648
10.65	450	450	3.660	5.319	19.47	435	0.37	21.00	1.034	1.034	0.425	9.295	0.477	0.691	12.719
10.65	500	500	3.294	4.788	15.77	435	0.37	21.00	1.149	1.149	0.435	9.505	0.603	0.776	14.291
10.65	550	550	2.994	4.352	13.03	435	0.37	21.00	1.264	1.264	0.475	10.345	0.794	0.891	16.400
10.65	600	600	2.745	3.990	10.95	435	0.37	21.00	1.379	1.379	0.500	10.870	0.993	0.996	18.339
10.65	650	650	2.534	3.683	9.33	435	0.37	21.00	1.494	1.494	0.550	11.920	1.278	1.130	20.805
10.65	700	700	2.353	3.420	8.05	435	0.37	21.00	1.609	1.609	0.650	14.020	1.743	1.320	24.299
10.65	800	800	2.059	2.992	6.16	435	0.37	21.00	1.839	1.839	0.700	15.070	2.447	1.564	28.792
10.65	900	900	1.830	2.660	4.87	435	0.37	21.00	2.069	2.069	0.800	17.170	3.528	1.878	34.574
10.65	1000	1000	1.647	2.394	3.94	435	0.37	21.00	2.299	2.299	0.850	18.220	4.622	2.150	39.572
10.65	1100	1100	1.497	2.176	3.26	435	0.37	21.00	2.529	2.529	0.885	18.955	5.818	2.412	44.399
10.65	1200	1200	1.372	1.995	2.74	435	0.37	21.00	2.759	2.759	0.900	19.270	7.039	2.653	48.836
10.65	1300	1300	1.267	1.841	2.33	435	0.37	21.00	2.989	2.989	0.900	19.270	8.261	2.874	52.906

Table 7 :Calculation of relative error % using GEV for total sulfur parameter

Global estimation variance															
Coal quality - total sulphur (%, adb)															
Mean	**h**	**l**	**_X**	**_Y**	**N**	**a**	**Co**	**C**	**h/a**	**l/a**	**Varians**	**σ^2E (r)**	**σ^2E (R)**	**σE (R)**	**% Relative Error**
0.10	50	50	29.356	42.826	1257.223	300	0.0001	0.00140	0.167	0.167	0.072	0.000	0.00000012	0.000	0.677
0.10	100	100	14.678	21.413	314.306	300	0.0001	0.00140	0.333	0.333	0.144	0.000	0.00000080	0.001	1.754
0.10	150	150	9.785	14.275	139.691	300	0.0001	0.00140	0.500	0.500	0.204	0.000	0.00000240	0.002	3.038
0.10	200	200	7.339	10.707	78.576	300	0.0001	0.00140	0.667	0.667	0.264	0.000	0.00000534	0.002	4.529
0.10	250	250	5.871	8.565	50.289	300	0.0001	0.00140	0.833	0.833	0.364	0.001	0.00001113	0.003	6.538
0.10	300	300	4.893	7.138	34.923	300	0.0001	0.00140	1.000	1.000	0.414	0.001	0.00001803	0.004	8.322
0.10	350	350	4.194	6.118	25.658	300	0.0001	0.00140	1.167	1.167	0.444	0.001	0.00002618	0.005	10.028
0.10	400	400	3.670	5.353	19.644	300	0.0001	0.00140	1.333	1.333	0.494	0.001	0.00003775	0.006	12.043
0.10	450	450	3.262	4.758	15.521	300	0.0001	0.00140	1.500	1.500	0.589	0.001	0.00005635	0.008	14.713
0.10	500	500	2.936	4.283	12.572	300	0.0001	0.00140	1.667	1.667	0.664	0.001	0.00007792	0.009	17.301
0.10	550	550	2.669	3.893	10.390	300	0.0001	0.00140	1.833	1.833	0.714	0.001	0.00010102	0.010	19.699
0.10	600	600	2.446	3.569	8.731	300	0.0001	0.00140	2.000	2.000	0.814	0.001	0.00013625	0.012	22.879
0.10	650	650	2.258	3.294	7.439	300	0.0001	0.00140	2.167	2.167	0.839	0.001	0.00016461	0.013	25.147
0.10	700	700	2.097	3.059	6.414	300	0.0001	0.00140	2.333	2.333	0.864	0.001	0.00019637	0.014	27.466
0.10	800	800	1.835	2.677	4.911	300	0.0001	0.00140	2.667	2.667	0.904	0.001	0.00026789	0.016	32.080
0.10	900	900	1.631	2.379	3.880	300	0.0001	0.00140	3.000	3.000	0.939	0.001	0.00035167	0.019	36.756
0.10	1000	1000	1.468	2.141	3.143	300	0.0001	0.00140	3.333	3.333	0.964	0.001	0.00044530	0.021	41.360
0.10	1100	1100	1.334	1.947	2.598	300	0.0001	0.00140	3.667	3.667	0.989	0.001	0.00055229	0.024	46.061
0.10	1200	1200	1.223	1.784	2.183	300	0.0001	0.00140	4.000	4.000	0.999	0.001	0.00066368	0.026	50.493
0.10	1300	1300	1.129	1.647	1.860	300	0.0001	0.00140	4.333	4.333	0.994	0.001	0.00077514	0.028	54.569

The results of the relative error calculation using the global estimation variance (GEV) for DHSA show that the relative error values for borehole spacing scenarios vary for both thickness and total sulfur parameters. The calculated relative error values for each variable determine the borehole spacing limit; therefore, each variable yields a different optimal spacing value, as presented in Table 6 and Table 7. To determine the optimal borehole spacing, the relative error thresholds for each resource category were applied: ≤10% for measured, ≤20% for indicated, and ≤50% for inferred categories. The relative error results from the GEV method were further visualized in a graph that plots the relative error values of each variable across the borehole spacing scenarios, as shown in Figure 5.

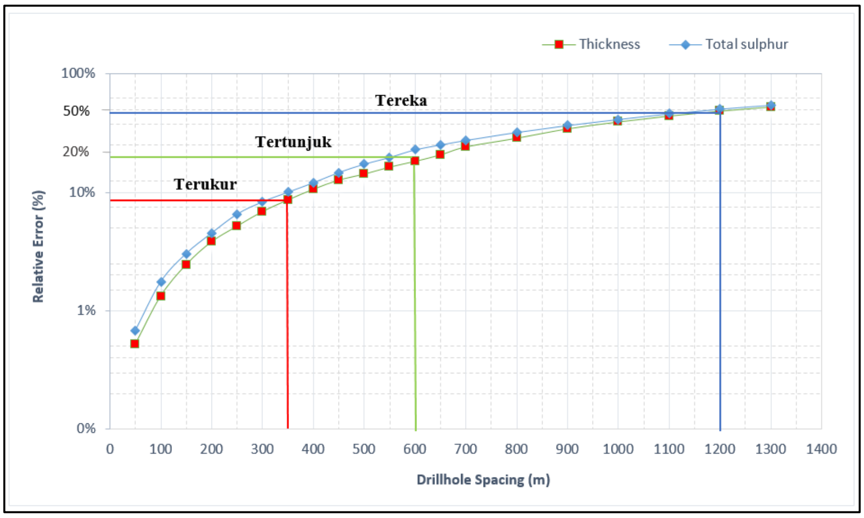

Fig 5 :Plot of relative error values with borehole scenario

The DHSA results using GEV indicate that the drill spacing derived from thickness and total sulfur parameters exhibits similar behavior, especially for larger spacing scenarios within the indicated resource category. These findings suggest that the currently applied drill spacing of 250 m based on SNI 5015:2019 can be extended to 350 m for future drilling in areas with comparable geological conditions. A comparison of the optimal drill spacing derived from GEV-based DHSA with SNI 5015:2019 is presented in Table 8. Notably, the measured, indicated, and inferred spacing values obtained from the GEV method are significantly wider than the standards proposed in SNI 5015:2019.

Table 8 :Comparison of borehole spacing optimization approaches

No.	Approaches	Variable	Drill hole spacing		
			Measured	Indicated	Inferred
1	Global Estimation Variance	Thickness (m)	350	600	1,200
		Total Sulphur (adb)	300	550	1,100
2	SNI 5015:2019	Moderate geological conditions	250	500	1,000

Despite the consistency of relative error trends, a key challenge arises from the limited sulfur data available. The lower density of sampling for the total sulfur parameter increases the statistical uncertainty of the GEV model, especially at wider spacing intervals. This condition may cause the relative error curves for sulfur to fluctuate more rapidly than thickness, potentially biasing the determination of optimal spacing. Ensuring a more uniform data distribution and increasing sulfur sampling frequency would improve the reliability of the GEV-based drill spacing analysis.

In addition, geological variability can greatly influence drill spacing, particularly in coal-bearing formations where structural features such as faulting, seam splitting, pinch-outs, or lateral thickness variations are common. Areas with structurally complex geology tend to have higher spatial variance, which increases estimation uncertainty even when borehole spacing is relatively narrow. Conversely, in geologically homogeneous zones, wider drill spacing may still produce acceptable estimation accuracy. Therefore, borehole spacing optimization must consider not only statistical thresholds from GEV calculations but also field-based geological assessments, ensuring that drilling grids are adapted to the degree of local stratigraphic continuity and structural disruption

4. Conclusion

The results of borehole spacing optimization using the Global Estimation Variance (GEV) method indicate that the recommended spacing for the measured (350 m), indicated (600 m), and inferred (1200 m) categories under moderate geological conditions is wider than those stipulated in SNI 5015:2019. Economically, wider drill spacing has meaningful implications. First, it directly reduces drilling costs—one of the most capital-intensive phases in exploration by lowering the number of boreholes required per unit area. This reduction can significantly increase project efficiency, particularly at the early exploration and resource delineation stages, when large areas must be tested and drilling budgets are often constrained. Additionally, fewer drill sites may shorten operational time and decrease logistical complexity, which is especially advantageous in remote or environmentally sensitive locations. However, it is equally important to acknowledge that broader spacing may increase geological risk in highly heterogeneous deposits, potentially necessitating later infill drilling during development. With respect to classification standards, the application of the GEV approach has shown that it can function as an effective complement rather than a replacement to the SNI framework. SNI 5015:2019 provides a regulatory baseline and offers uniformity in resource reporting, which is crucial for compliance, legal defensibility, and comparability across projects. The GEV method adds geostatistical rigor by incorporating population variance and sill values into decision-making, enabling more data-driven confidence in the categorization of coal resources. Therefore, while SNI-based classification remains the formal reference for Indonesian resource evaluation, the GEV method can refine borehole placement strategies by enabling adaptive spacing grounded in observed geological variability. In practice, the GEV approach can be used to justify deviations from standard spacing where geological conditions, data density, and acceptable relative error thresholds support it, ultimately enhancing classification confidence without undermining regulatory standards.

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