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Classification of Coal Resources Using Drill Hole Spacing Analysis (DHSA)

Iskandar Zulkarnain and Waterman Sulistyana Bargawa
Master of Mining Engineering, UPN Veteran Yogyakarta, Jl. SWK 104 Yogyakarta 55283, Indonesia

Abstract: The classification of coal resources generally is based on geometric factors and the complexity of geological structures. The classification has not considered coal quality factors such as ash content, sulphur content, caloric value. The development of international classification standards has required a geostatistical analysis for the estimation and classification of coal resources. The purpose of this research is to apply geostatistics method to determine optimal drill hole distance, and to analyze classification of coal resource based on data of coal quality and quantity. Based on global estimation variance (GEV) approach from geostatistics, relative error value was obtained. Drill hole spacing analysis (DHSA) results in optimal drill hole spacing on each coal seam for the coal resources classification. Estimation using kriging block results in the value of kriging relative error. Coal resources classification was based on relative error of 0-10% for measured resources, 10-20% for indicated resources and > 20% for inferred resources. Based on a case study in a coal field consisting of three coal seams, the geostatistical approach produced the smallest distance on seam-3 as the optimal borehole range in the research area. This classification yields a greater area of influence than the SNI standard on simple geological complexity.

Key words: Geostatistics, bore hole spacing analysis, SNI (5015:2011), GEV, kriging relative error.

1. Introduction

Several international classification systems [1-4] have been developed in the past, the main ones are the American USGS Circular 831 (USGS, 1980) and SME Guide (SME, 1999), the South-African SAMREC Code (SAMREC, 2000), the Canadian CIM Guidelines (CIM, 2000) and National Instrument 43-101 (CSA, 2001), the European Code (EURO, 2002), the Australasian JORC Code (JORC, 2012), and Indonesia SNI (5015:2011). All these codes are broadly similar, although some differences in their definitions remain. The JORC code is with little doubt the one that has found wider acceptance in countries that do not have their own code. Generally, the basic classification of resources and reserves for coal is a factor of quantity, geometry, and the complexity of geological structures [5]. Limiting factors do not consider coal quality factors such as ash content, sulphur content, caloric value.

Geometry parameter, and coal quality aspects become an important aspect to determine the classification of coal resources [6]. Applying the approach to any coal basin with certain geological settings will have certain resource classification parameters as well. The area of influence on each coal basin will differ in different geological settings [7, 8]. The development of resource classification standards and coal reserves requires the use of geostatistical approaches. Coal resources classification research has been widely developed using a geostatistical approach [9-13].

2. Objective

The objective of this research is to make the classification of coal resources based on global estimation variance (GEV) approach related to drill hole spacing analysis. The results of the analysis will be compared with SNI 5015:2011 to evaluate the

Corresponding author: Waterman Sulistyana Bargawa, Ph.D., Mr., research field: geostatistics and mining environment.

classification of resources.

3. Methods and Material

GEV yields global relative error values [14, 15]. The nomogram determines the value of the extension variance (σ_K^2) dot against the square plane for the spherical model with the variance nugget being 0 and the sill value is 1 (see Fig. 1). Furthermore, point variance estimates of the σ_K^2 (r) field considering the value of the nugget variance and sill of each parameter [15]:

$$\sigma_E^2(r) = C0 + \left(C * \sigma_e^2\right) \tag{1}$$

The estimation variance value divided by the number of blocks (N) yields a GEV value:

$$\sigma_E^2(R) = \sigma_E^2(r) / N \tag{2}$$

The calculation of GEV values yields a relative error:

$$\text{Relative error} = \pm 1.96 \cdot \sigma_E \cdot 100\% / \text{mean} \tag{3}$$

The GEV obtained based on the nomogram is then used to estimate the relative error value. Then plotting between the relative error values against the drill hole spacing is to create a drill hole spacing analysis (DHSA) graph [6]. The DHSA graph analysis considers the value of drill spacing and relative error when it reaches 10%, 20% and 50% as the optimum distance. Based on the DHSA graph and relative error values, the distance or area of influence for measured, indicated, and inferred resources can be evaluated.

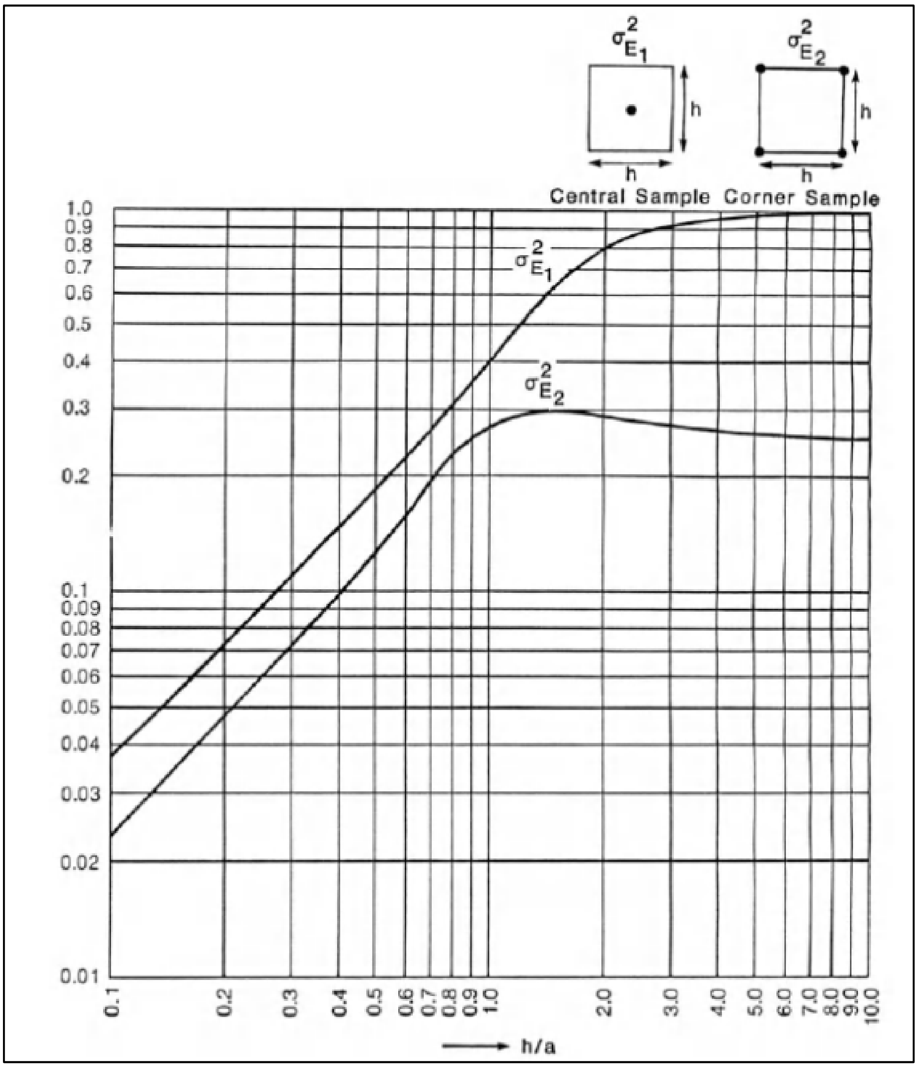

Fig. 1 Nomogram of extension variance/estimation [14, 15] values (σ_e^2), point to square area for spherical models.

Geostatistical approach is generally used for estimation of ore mineral grade [16-18]. Another result of kriging is the use of kriging relative error of the ordinary kriging estimation method for classification of coal resources [19]. The classification of coal resources uses the value of the kriging relative error of the ordinary kriging estimation method. Kriging is an estimation method of regionalized variable at point, or volume by using criteria to minimize variance estimation. The kriging procedure needs to consider the following [20]:

(a) estimated value using the equation:

$$Z^* = \sum_{i=1}^{n} w_i \cdot Z_i \quad (4)$$

(b) equation to calculate the weight, w_i:

$$\sum_{i=1}^{n} w_i . \bar{\gamma}(v,v) + \mu = \bar{\gamma}(v,V) dan \sum_{i=1}^{n} w_i = 1 \quad (5)$$

(c) Kriging variance can be expressed by equation:

$$\sigma_K^2 = \sum_{i=1}^{n} w_i . \bar{\gamma}(v,V) - \bar{\gamma}(V,V) + \mu \quad (6)$$

Based on kriging variance we get the following equation:

$$\sigma_K^2 = \bar{\gamma}(V,V) - [w]^{-1} \cdot [M] \quad (7)$$

(d) kriging relative error is expressed by equation:

$$\text{kriging relative error} = \pm 1.96 \frac{\sigma_K}{Z^*} \times 100\% \quad (8)$$

where:

Z^*: estimated value

σ_K^2 : kriging variance

σ_K: kriging standard deviation

The calculation of the value of kriging relative error is obtained from the standard deviation value of the block unit divided by the value of the kriging estimate of the block unit, multiplied by the 95% confidence interval factor of 1.96 while the standard deviation value is the square root of the estimated variance value obtained from the ordinary kriging method.

According to Ref. [21] the classification of resources (Table 1) is based on confidence interval and tolerance of relative error.

Meanwhile, according to Ref. [24] the classification of resources and coal reserves is an effort to group resources and coal reserves based on geological confidence and economic feasibility. Table 2 shows the classification of resources based on the distance of the point of information according to geological conditions.

The research area is located in East Kalimantan Province Indonesia. Fig. 2 shows a map of drill hole distribution in the study area.

Based on the geological model the research area consists of 3 (three) coal seams.

Table 1 Resource classification [22, 23] based on drill hole distance and error tolerance.

Resource classification	Max. extrapolation	Max. spacing between information point	Error tolerance
Measured	500 m	+1 km < 500 m	0 - 10 %
Indicated	1,000 m	+2 km < 1 km	10 -20 %
Infernal	2,000 m	+4 km	> 20%

Table 2 Resource classification [22] based on distance of information points according to geological condition.

Geological condition	Criteria (m)	Resources		
		Inferred	Indicated	Measured
Simple	Distance of information point	1,000 < x ≤ 1,500	500 < x ≤ 1,000	x ≤ 1,500
Moderate	Distance of information point	500 < x ≤ 1,000	250 < x ≤ 500	x ≤ 250
Complex	Distance of information point	200 < x ≤ 400	100 < x ≤ 400	x ≤ 100

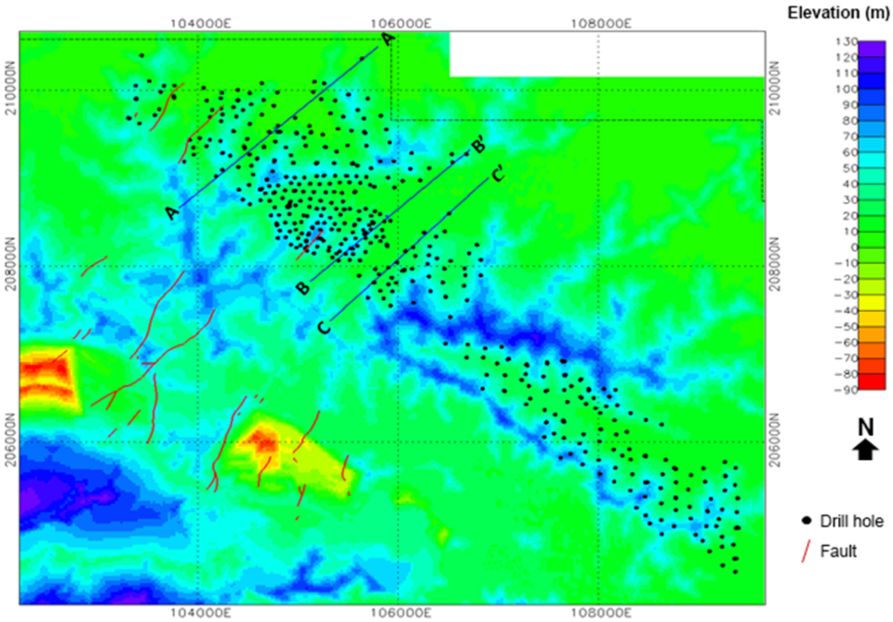

Fig. 2 Map of the distribution of drill hole in the study area.

4. Results

Table 3 shows descriptive statistics on coal seam. Variogram model is spherical used for all data of coal quality (ash, total sulphur, relative density, calorific value) and thickness for the three seams of coal.

Table 4 shows the variographic results for each coal quality parameter.

Table 5 shows the calculation of relative error values by the method of GEV. The research area consisted of 3 (three) coal seams. DHSA and GEV methods produce optimal borehole spacing at each seam. The classification of measured resources in Seam-1 is 950 m at relative error of 10%, 1,650 m for indicated resources at relative error of 20%, and 2,650 m for inferred resources at relative error of 50%. At Seam-2 the classification of measured resources is 1,150 m at relative error of 10%, 1,850 m for indicated resources at relative error of 20%, and 4,300 m for inferred resources at relative error 50% while the classification of measured resources at seam-3 is 750 m at relative error of 10%, 1,100 m for indicated resources at relative error 20% and 2,150 m for inferred resources at relative error of 50%. Fig. 4 shows a drill hole spacing analysis (DHSA) graph for Seam-3.

Fig. 4 is an example of DHSA chart analysis to determine the optimum distance in Seam-3 with classification of measured resources being 750 m, 1,100 m for indicated resources and 2,150 m for inferred resources. Fig. 5 shows a histogram of comparison of measured, indicated, and inferred resource classification based on the borehole distance (area of influence). Relative error values are obtained from the results of reading DHSA graphics for Seam 1, Seam 2, and Seam 3. Drill hole distance based on the calculation of relative error values showed higher values compared with the standard of SNI.

Based on the comparison of measured, indicated, and inferred resource classifications in Fig. 5, the optimal distance for the research area using the result of the relative error value analysis on Seam 3: distance measured resource classification is 750 m at ER 10%, indicated is 1,100 m at ER 20%, and inferred is 2,150 m at ER 50%. Based on Fig.5 the classification of measured resources in this study produces the same distance or area of influence as Saraji, but is higher than the Peak Down Bowen Basin, Coal Guideline and SNI. For the classification of indicated resources, this research is more conservative than Saraji and Peak Down Bowen Basin, but the distance is higher than the

Table 3 Descriptive statistics for Seam-1, Seam-2, and Seam-3.

No	Parameter	Seam 1					Seam 2					Seam 3				
		Thick	CV	TS	RD	Ash	Thick	CV	TS	RD	Ash	Thick	CV	TS	RD	Ash
1	Mean	9	4.408	0.3	1.3	2.5	17	4.742	0.2	1.3	2.1	2.2	4.712	0.9	1.3	4.1
2	Median	10.5	4.320	0.3	1.3	2.5	19.9	4.573	0.2	1.3	2.1	2.3	4.575	0.2	1.3	3.7
3	Mode	11	4.218	0.2	1.3	2.7	26	5.470	0.1	1.3	2.2	2.7	4.393	0.2	1.3	3.1
4	Variance	11.9	61.763	0	0	0.2	65.1	176.226	0	0	0.3	0.5	188.591	1.5	0	1.9
5	Standard Deviation	3.5	248.5	0.2	0	0.5	8.1	419.8	0.2	0	0.6	0.7	434.3	1.2	0	1.4
6	Minimum	0.7	4,110	0.1	1.3	1.2	2	4.252	0.1	1.3	1.2	0.3	4.073	0.1	1.3	2
7	Maximum	16	5,170	1.1	1.3	4.1	28.8	5.593	0.8	1.3	3.7	5	5.762	4	1.4	9.5
8	Count	213	36	36	36	36	134	67	67	67	67	330	49	49	49	49
9	Coefficient of variation	0.4	0.1	0.5	0	0.2	0.5	0.1	0.7	0	0.3	0.3	0.1	1.4	0	0.3
10	Weighted avg		4.400	0.3	1.3	2.5		4.597	0.2	1.3	2.1		4.675	0.7	1.3	40
11	sign. weighted Average		0	0	0	0		0	-0.2	0	0		0	-0.2	0	0

Table 4 Variogram parameter using spherical model.

Seam	Parameter	Co	Sill	Range	CV
1	Ash	0	0.24	950	0.2
	Calorific value	0	61763	1,600	0.06
	Relative density	0	0.00033	2,550	0.01
	Thickness	3.4	8	1,800	0.38
	Total sulphur	0	0.038	1,300	0.47
2	Ash	0	0.3046	850	0.26
	Calorific value	0	215000	3,000	0.09
	Relative density	0.000225	0.000125	735	0.01
	Thickness	11	50	1,800	0.48
	Total sulphur	0	0.0228	2,950	0.7
3	Ash	0	1.9	1,650	0.34
	Calorific value	0	210000	3,010	0.09
	Relative density	0.00006	0.000339	1,300	0.02
	Thickness	0.14	0.47	1,700	0.33
	Total sulphur	0	0.02111	2,820	1.43

Co: nugget variance, CV: coefficient of variation

Table 5 Relative error value calculation using GEV method.

Parameter	Mean	h	l	_X	_Y	N	a	Co	C	h/a	l/a	Varians	σ^2Er	σ^2ER	σER	Error
	9	100	100	54	49	2,646	1,800	3.4	8	0.056	0.056	0.020	3.560	0,001	0.037	0.80%
Thickness	9	200	200	27	25	6,75	1,800	3.4	8	0.111	0.111	0.040	3.720	0,006	0.074	1.62%
	9	300	300	18	17	306	1,800	3.4	8	0.167	0.167	0.056	3.848	0,013	0.112	2.44%
	2.5	100	100	54	49	2,646	950	0	0.24	0.105	0.105	0.030	0.007	0,000	0.002	0.13%
Ash	2.5	200	200	27	25	675	950	0	0.24	0.211	0.211	0.070	0.017	0,000	0.005	0.40%
	2.5	300	300	18	17	306	950	0	0.24	0.316	0.316	0.110	0.026	0,000	0.009	0.74%
	4.408	100	100	54	49	2,646	1,600	0	61.763	0.063	0.063	0.023	1389.668	0,525	0.725	0.03%
CV	4.408	200	200	27	25	675	1,600	0	61.763	0.125	0.125	0.045	2779.335	4,118	2.029	0.09%
	4.408	300	300	18	17	306	1,600	0	61.763	0.188	0.188	0.065	4014.595	13,120	3.622	0.16%
	1.3	100	100	54	49	2,646	2,550	0	0.00033	0.039	0.039	0.011	0.000	0,000	0.000	0.01%
RD	1.3	200	200	27	25	675	2,550	0	0.00033	0.078	0.078	0.021	0.000	0,000	0.000	0.02%
	1.3	300	300	18	17	306	2,550	0	0.00033	0.118	0.118	0.042	0.000	0,000	0.000	0.03%
	0.3	100	100	54	49	2,646	1,300	0	0.038	0.077	0.077	0.025	0.001	0,000	0.001	0.36%
TS	0.3	200	200	27	25	675	1,300	0	0.038	0.154	0.154	0.050	0.002	0,000	0.002	1.00%
	0.3	300	300	18	17	306	1,300	0	0.038	0.231	0.231	0.080	0.003	0,000	0.003	1.88%

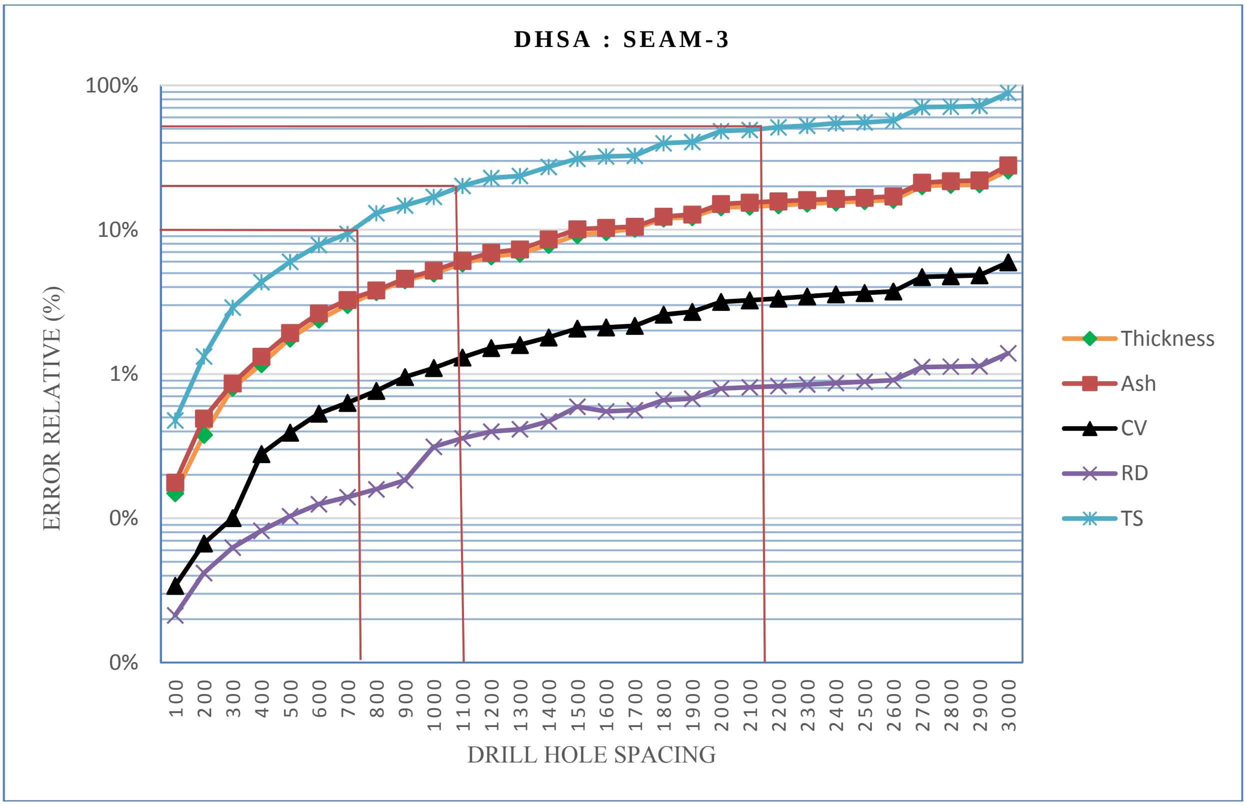

Fig. 3 Drill hole spacing analysis (DHSA) graph of Seam-3.

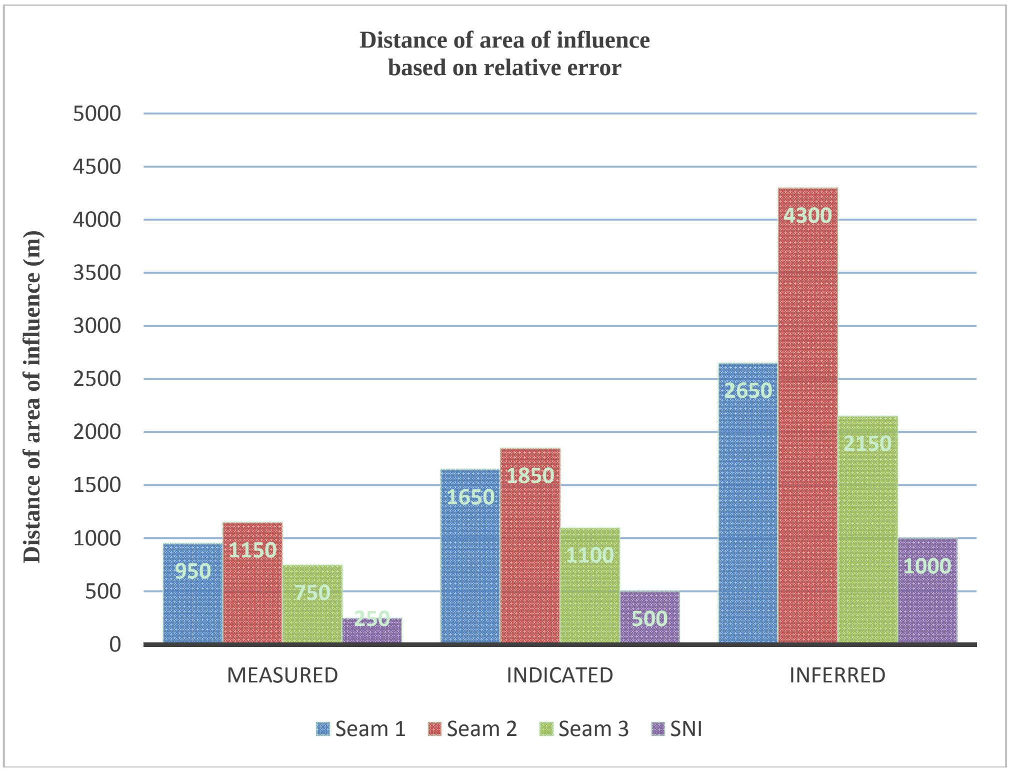

Fig. 4 Area of influence (or distance) on coal resource classification.

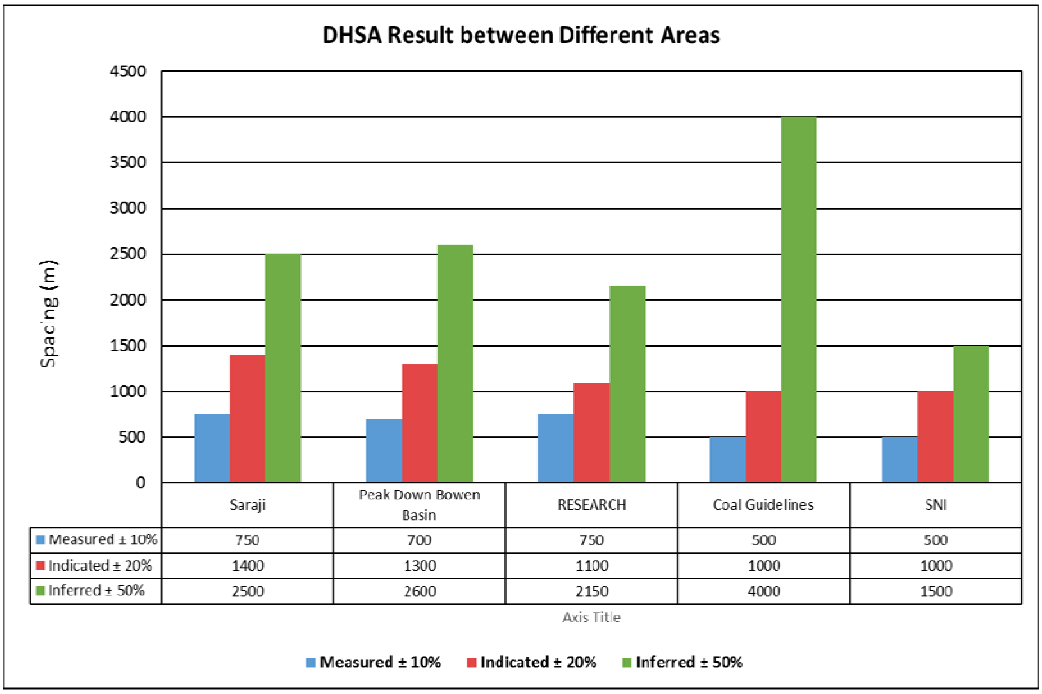

Fig. 5 Various studies: Saraji, Bowen Basin (Bertolli 2013), coal guideline, and SNI 5015:2011 to compare the optimum drill range for resource classification based on relative error.

Table 6 Example results of estimation and resource classification on CV parameters of Seam-1.

X	Y	CV (Calorific value)				
		Estimate	Variance	Stdv	Relative error	Classification
105688	208144	4614.56	75608.6	274.9702	11.67915	Indicated
105938	208144	4551.02	72280.6	268.8505	11.57866	Indicated
105438	208394	4516.63	69172	263.0057	11.41318	Indicated
105688	208394	4542.44	65188	255.3194	11.01668	Indicated
105938	208394	4523.78	71376	267.1629	11.57526	Indicated
105188	208644	4456.67	74910.8	273.6984	12.03699	Indicated
105438	208644	4479.73	67627.5	260.0529	11.37800	Indicated
105688	208644	4471.24	61656.7	248.3077	10.88474	Indicated
105938	208644	4423.43	65807	256.5288	11.36666	Indicated
105688	208894	4203.44	72018.3	268.3623	12.51332	Indicated
105938	208894	4175.06	64312.4	253.5989	11.90531	Indicated

Coal Guideline and SNI. As for the classification of inferred resources, this research is more conservative than other methods.

Here is a discussion of the value of kriging relative error for classification of coal resources. Based on Eq. (3) calculation of kriging value relative error is obtained from standard deviation value of unit block with 95% confidence interval. Table 6 shows the results of resource classification based on the relative error kriging value.

High value of kriging variance will cause high relative error value. The highest relative error values in coal quality parameters are total sulphur > 100% and ash > 50% included in inferred resource classification. Geologically high sulphur and ash contents are associated with sediments deposited in marine-brackish water environments. Fe element in the marine-brackish water environment is present in large numbers, whereas bacterial activity plays a major role in the formation of high sulphur.

4. Conclusion

(a) Based on comparison of measured, indicated, and inferred resource classification at the most optimum distance at Seam-3 with distance of 750 m measured resource classification at 10% relative error, indicated 1,100 m at 20% relative error, and inferred 2,150 m at ER 50%.

(b) The results of this study indicate the area of influence or distance is higher than SNI, but it is still within range of other methods.

(c) High value of kriging variance will cause high relative error value. The high relative error values in coal quality in the study area were totally sulphur (> 100%) and ash (> 50%) included in inferred resource classification. Geologically high sulphur and ash contents are associated with sediments deposited in the brackish-water environment.

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