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CLASSIFICATION OF GEOLOGICAL CONDITIONS USING GEOSTATISTICS IN COAL FIELD, SANGATTA, EAST KALIMANTAN, INDONESIA

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ABSTRACT

Coal deposits at different locations with various geological conditions, have distinct continuity and level of data density. Thus, the justification descriptive within the classification does not depict actual data conditions. It is therefore necessary to justify density level data using geostatistical classification quantitatively. Quantitative classification is taking into account the spatial variability of the data to quantify the level of data density by calculating the value of the variogram range (data geometry and quality of coal). Sangatta coal field area is divided into two zones, the western and the eastern zone. Based on the qualitative analysis of geology, west zone is classified into moderate geological conditions and the eastern zone is classified into complex geological conditions. Based on the analysis of the variogram, kriging and kriging variance, it is known that the west zone of coalfield Sangatta has the geological conditions of moderate (based on SNI 5015, 2011), with a classification category coal resources that, inferred, Indicated and measured, while the eastern zone has geological conditions are complex (based on SNI 5015, 2011), with the coal resource classification categories, Indicated and inferred.

KEYWORDS: Level Data Using Geostatistical Classification Quantitatively, Classification is Taking into Account the Spatial Variability of the Data, Calculating the Value of the Variogram Range

INTRODUCTION

The study is carried out in the Sangatta Coalfield, Kalimantan, Indonesia, which has a good potential for coal production. As this coal field has already been explored in detail, it has a good base of coal data for coal geological studies. The Sangatta seam, the most important seam in the area, has the largest volume of documented geological information in the coal data base. Any models resulting from this study can hopefully be applied to other seams in this coalfield and to other coalfields in Indonesia; at least in those basins which have similar geological conditions.

This study is based on the fact that the classification procedure for geological conditions in the Indonesian National Standard 5015, 2011 (SNI 2011) is qualitative and a mere interpretation of a competent person’s opinion. Geostatistical approach, as a quantitative method, has been recognized, for more than 40 years, of use as an alternative method for classification of the geological conditions and also the classification and estimation of coal resources. Additionally, geostatistical methods can be used to evaluate and optimize exploration drill holes pattern and spacing based on the relative error generated by the estimated coal thickness and quality. The research location used for the case study is Balikpapan Formation coal deposits in the area of Sangatta coal field, East Kalimantan. Data supporting this research was provided by PT. Kaltim Prima Coal, which include spreadsheet data coordinates and elevation of the drill holes, the thickness and quality of coal (ash content, sulfur total, and the calorific value), and dataset drill holes associated with AutoCAD files from crop line per seam, concession boundaries, a map of the local geology, and drilling and sampling locations.

Statistical descriptions are used to verify the thickness and quality of coal. Then, the variogram construction and fitting models are made to create spatial models of coal thickness and quality. Classification and geostatistical estimation employs the Kriging method, which is used to estimate the thickness and quality of coal. Variance estimates, as a result of kriging estimate, is used to calculate the estimated error of relatives blocks for each variable such that the classification of coal resources can be obtained. Furthermore, the results were compared using SNI 5015, 2011, where coal resource classification procedure is based on the complexity of geological conditions. Besides the optimization of exploration drill hole, spacing is done by analysis of the relative error of each variable spacing or coal for different patterns and supports the samples. The classification of the geological conditions and coal resources based on the relative error is expected to provide an alternative in determining the classification of coal resources in coal deposits.

Classification of Coal Resources depends on the level of geological confidence in the form of the density, quality of data and the complexity of the geology. Geological complexity is caused by several processes:

- The processes of syn- depositional geology, geological process which ran concurrently with the formation of coal: differences in sedimentation velocity and morphology of the base in the basin, the pattern of preconceived structure and environmental conditions when coal formed. Syn-dep process includes:
  - Geometry and structure (in the form of splitting, washout, thinning, thickening, wedge out, syn-dep faulting, etc.)
  - Composition (macerals, minerals, sulfur, etc.)
  - Establishment of quality (content of mineral matter, Sulphur, etc.)
- Geologic processes post-depositional, the geological processes that take place after the coal seam is formed, comprising:
  - Geological structures (faults, folds, joints / cleats, dips, etc.)
  - Coal rank (igneous intrusions, heat flow, maturation)
  - Epigenetic formations minerals (pyrite, carbonate, etc.)

In geological conditions, geological characteristics in SNI 5015, 2011 can be grouped into simple, moderate and complex (see table 2). Classification of resources and reserves of coal by the Indonesian National Standard (SNI) is based on the level of geological confidence and feasibility studies. The grouping contains two aspects: geological and economic aspects (see Figure 1)

GEOSTATISTICAL METHODS

The first stage of any geostatistical analysis is Exploratory Data Analysis. *(Zach Casley, Oli Bertoli, Clare Mawdesley and Doug Dunn, 2010)*. Two of the main purposes of the Exploratory Data Analysis process are:

- To check the validity of domaining decisions, with respect to the underlying assumptions of statistical homogeneity of the spatial distribution of the coal characteristics; and,
- To identify outliers in the data, that is, sample values that are inconsistent with the underlying spatial distribution for the variable of interest and may impact the calculation of the experimental variograms.

The development of appropriate geological domains is an integral part of the decision making process concerning the definition of 'domains of stationarity'. The term stationarity is linked, in a sense, to the statistical homogeneity within a given domain. Domains of stationarity are generally closely related to geological, structural and/or weathering units. Exploratory Data Analysis can be performed for each variable in each seam/domain combination by analyzing linked:

- Location map of samples;
- Histogram of sample values; and,
- Experimental omnidirectional or directional variograms obtained from the selected samples.
- Kriging and Kriging Variance

The examination of the linked scatter diagrams between the variable of interest and the spatial coordinates is particularly helpful in evaluating the level of statistical homogeneity within a given domain and rapidly identifying potential sub-domains, and/or the presence of outliers. Kriging interpolation is a spatial mathematical model. It is a method of interpolation, which predicts unknown values by computing a weighted average of the known values in the neighborhood of the point. This method uses variogram to express the data spatial variation, and it minimizes the error of predicted values. The essence of it is an improvement of weighted distance; it is still a linear interpolation method. The algorithm is as follows:

Assuming that the study area is A, Z(x)is the value at point x, give the values $Z(x_1),...,Z(x_n)$ at sampling points $x_1,...,x_n$, then the value of unobserved point x_o is calculated from a linear combination of the observed values:

$$Z(x_0) = \sum_{i=1}^{n} \lambda_i Z(x_i) \qquad \textbf{(1)}$$

Where λ_i is the weight at sampling point x_i. It can reflect the structural "proximity" of samples to the estimation location x_o.

Seam thickness variation is consistent with regionalized variables, which has a characteristic of spatial autocorrelation. In geostatistics, regionalized variables can be expressed by variogram. In this paper, we use the ordinary Kriging interpolation method, the experimental variogram formula is:

$$r^*(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \qquad \textbf{(2)}$$

Where $N(h)$ is the number of pairs separated by vector h, vector h is lag distance.

After the experimental variogram is computed by formula (2), we usually observe the distribution of experimental variogram and then identify a reasonable empirical variogram model based on the experimental variogram distribution or prior knowledge. The most commonly used empirical variogram models are spherical model.

Kriging is an interpolation technique that minimizes the squared error between the estimated value and the unknown true value. *(D.S.F. Silva and J. B. Boisvert, 2014)*. The resultant error variance, also known as the kriging variance, is dependent only on the estimation location, the position of samples, and the variogram. The most common classification approaches, based on the review conducted, require the definition of thresholds to differentiate categories. The advantage of using kriging variance as the criterion for classification is the consideration of the spatial structure of the variable and the redundancy between samples; however, it often produces classification maps with undesirable artifacts. Artifacts are common near sample location as the kriging variance is very low, resulting in patches of Measured blocks in Indicated zones. Moreover, the kriging variance does not account for the proportional effect which is a common characteristic of earth sciences data and may be important in the high-grade zones where the variance is high.

Blackwell (1998) presented an argument for introducing the Relative Kriging Variance (RKV); the ratio of kriging variance and the kriged estimate squared. From this the Relative Kriging Standard Deviation (RKSD) is defined as the square root of the RKV. The RKSD is plotted against the number of samples used in the kriging of the block. The threshold values for the RKSD are selected arbitrarily, but based on experience, to separate the measured, indicated and inferred categories.

GEOLOGY OF SANGATTA COAL SEAM

The Sangatta coal seam, which contains high volatile bituminous coal and is the most important seam in the Sangatta Coalfield, was deposited within a Late Middle Miocene fluvial system that occupied the northern Kutei Basin, Indonesia. A study of clastic sedimentology, coal petrology of standard and etched coal samples, thickness and coal quality parameters, integrated with a geostatistical analysis, identified the depositional environment of the seam. The previous study by Nas, 1994, indicated that the coal seam was deposited within the floodplain of a mixed-load fluvio-deltaic system with the rivers flowing southeastward. Local changes in sedimentary facies below and above the Sangatta seam caused variations in the local rates of subsidence and compaction which, in turn, controlled the peat swamp morphology and coalification pattern. The morphological variations governed hydrologic conditions in the swamp which, in turn, influenced peat accumulation and subsequent geological processes acting on, and within, the peat. These factors also influenced seam thickness, maceral composition and coal quality parameters. The Sangatta seam has an average thickness of 6 m. The coals are characterized by a high vitrinite (average of 9 1 %), low liptinite (average of 3 %), low inertinite (average of 3 %), very low mineral matter (average of 2%) and low sulphur (average of 0.4%).

Sangatta coal field area is divided into two areas, the western and the eastern zone. Based on the analysis of geological, west zone is classified in moderate geological conditions; the conditions of coal sludge sedimentation deposited in more varied conditions and to a certain extent have been changed after the sedimentation and tectonics. Fault and folds are not many, so are faulting and folding the resulting relatively moderate. This group is also characterized by low the dip of the seam, thickness and lateral variations and the development of parting, but its distribution is still can be followed up to hundreds of meters.

While the eastern zone is classified in complex geological conditions, the conditions of coal deposited in the system sedimentation complex or resulting in the extensive deformed tectonic, it causes the coal seam thickness vary. The quality of coal is heavily influenced by the changes that occur when sedimentation takes place or at the post-deposition, such as division or damage of seam (wash out). Faulting, folding and overtune folding arising by tectonic activity, and its common so coal seams difficult correlated. Strong folding also results coal seam steep. Laterally, spread a coal seam limited and can be followed up to tens of meters

RESULT AND DISCUSSIONS

Conclusion geology of the coal seam:

Table 1

a. The Western Zone	b. The Eastern Zone
Thicker	Thinner
Less structures	More structures
Less variable	More variable
More continuous	Less continuous
Less partings	More partings
Clean coal	Higher ash
Less sulphur	Sulphur is variable

After observing in detail the area of field research locations of Sangatta coal seam, with reference to the classification of the geological conditions of SNI 5015, 2011 and evidence of geological studies above, it can be concluded that the area of the Sangatta coal field can be divided into two conditions, the geological conditions of moderate and complex. Group of complex geological conditions in the eastern part of the area, while the moderate geological conditions that are in the western area.

Statistical Analysis and Geostatistical

Statistical analysis of multiple parameters of coal seam, obtained from field measurements and laboratory work during the exploratory phase of coalfield Sangatta conducted to systematically evaluate the spatial variation of each parameter.

West Zone

The data to be analyzed is 426 boreholes. The drill data obtained is the thickness of the coal seam, which subsequently made with the histogram graph of statistical zone in the west analysis to obtain the values of the statistical variables. Variogram analysis for variable thickness of the Sangatta coal seam using lag distance of 60 m and lag tolerance 30 m, producing Range 528, Sill 1,722 and Nugget Effect 6.97. Variogram models used are spherical. (Figure 4)

This analysis is supported by geostatistical software that is SGeMS (Stanford Geostatistical Modeling Software). Estimated value of the levels in units of a block model with a grid of 200 × 200 × 1 m using Ordinary Kriging method, which aims to get the value estimation and kriging variance of the thickness of the zone. Kriging will estimate each variable in each unit so that each grid block model will have an estimated value. Results with Ordinary Kriging estimation is shown in the Figure 5.

Eastern Zone

The data to be analyzed is 818 boreholes. The drill data obtained is the thickness of the coal seam, which subsequently made with the histogram graph of statistical analysis to obtain the values of the statistical variables. Variogram analysis for variable thickness of the Sangatta coal seam uses lag distance of 40 m and lag tolerance 20 m, producing Range 277, Sill 3.444 and Nugget Effect 4.51 (Figure 7) Variogram models used are spherical. Results with Ordinary Kriging estimation is shown in the Figure 8.

This analysis is supported by geostatistical software that is SGeMS (Stanford Geostatistical Modeling Software). Estimated value of the levels in units of a block model with a grid of 200 × 200 × 1 m using Ordinary Kriging method, which aims to get the value estimation and kriging variance of the thickness of the zone. Kriging will estimate each variable in each unit so that each grid block model will have an estimated value. Results with Ordinary Kriging estimation is shown in the picture below.

Comparison between geostatistical approach and based on SNI 5015, 2011 for the western zone indicate similarities, which is a moderate geological conditions. For the eastern zone, the data points to complex geological conditions. For the classification of coal resources seen the difference.

Density Data:

West Zone = 60m

East Zone = 50m

Range Variogram For Coal Measured Resources

West Zone = 100m

Eastern Zone = 50m

Kriging Variance:

Based on the results of Kriging variance, showed the following results:

- West Zone gives the classification results of Measured Coal Resource, Indicated Coal Resource and Inferred Coal Resource. West Zone, with an exceptionally dense drill hole spacing, and expected to produce a measurable resource classification, is apparently compatible with the geostatistical analysis which also produces measured, indicated and inferred coal resources. The similarity is due to the fact that geological conditions in the west zone is “moderate”.
- Eastern Zone gives the classification results of Inferred Coal Resource and Indicated Coal Resource.

Eastern Zone, which densities spaced drill holes were classified as very dense, is expected to produce a measured resource, but the results of geostatistical analysis seems to point towards Indicated Coal Resource and Inferred Coal Resource. This is due to complex geological conditions, as discussed in the previous discussion.

FIGURES AND TABLE

Table 2: Parameter Aspects vs. Geological Conditions (SNI 5015, 2011)

Parameter	Geological Conditions		
	Simple	Moderate	Complex
I. Sedimentation Aspects			
Thickness variations	not varied	varied	very varied
Continuity	Thousand meter	Hundred meter	Tens of meter
Splitting	almost nothing	several	many
II. Tectonically Aspects			
Faults	almost nothing	rarely	close
Folds	No folded	folded	Strong folded
Intrusions	no influence	influential	Very influential
Dip	Gently dipping	inclined	Steeply pitching
III. Quality Aspects			
Quality Variations	not varied	varied	very varied

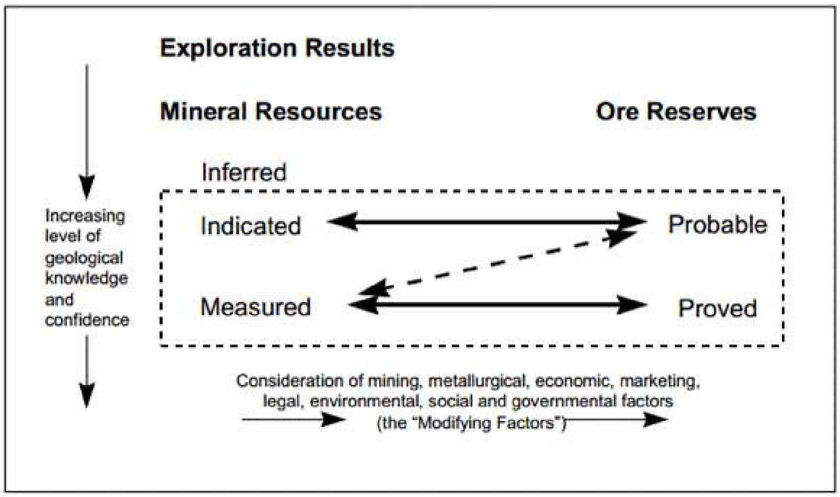

Figure 1: Relationship between Resources and Coal Reserves (SNI 5015: 2011)

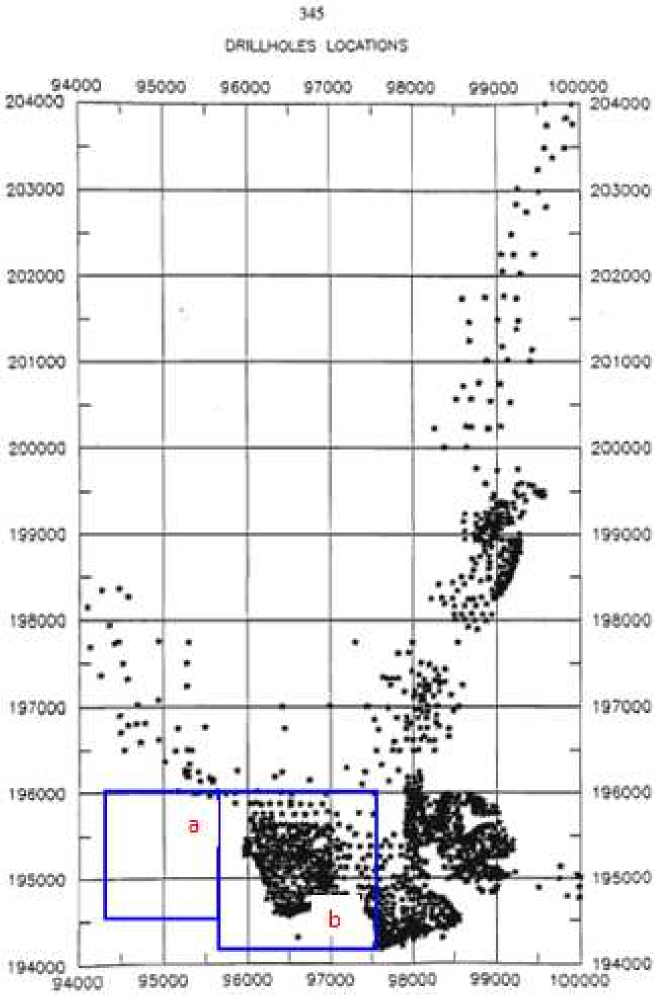

Figure 2: Map Locations of Drill Holes in Sangatta Coalfield (a) Western Zone, (b) The Eastern Zone

N	Valid	426
	Missing	0
Mean		6,7933
Std. Error of Mean		0,13862
Median		6,8300
Mode		7,49
Std. Deviation		2,86116
Variance		8,186
Skewness		-0,025
Std. Error of Skewness		0,1 8
Kurtosis		0,082
Std. error of Kurtosis		0,236
Range		14,14
Minimum		0,40
Maximum		14,54
Sum		2893,96
COV		0,421

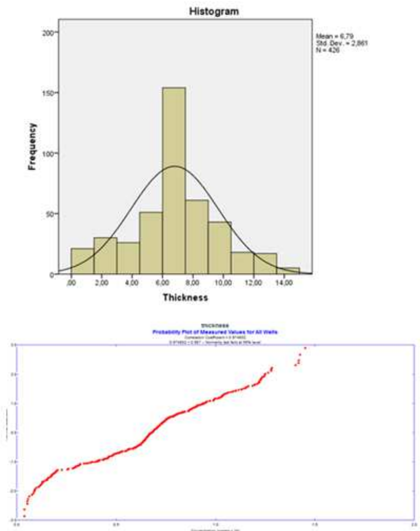

Figure 3: Basic Statistical Analysis for Western Zone

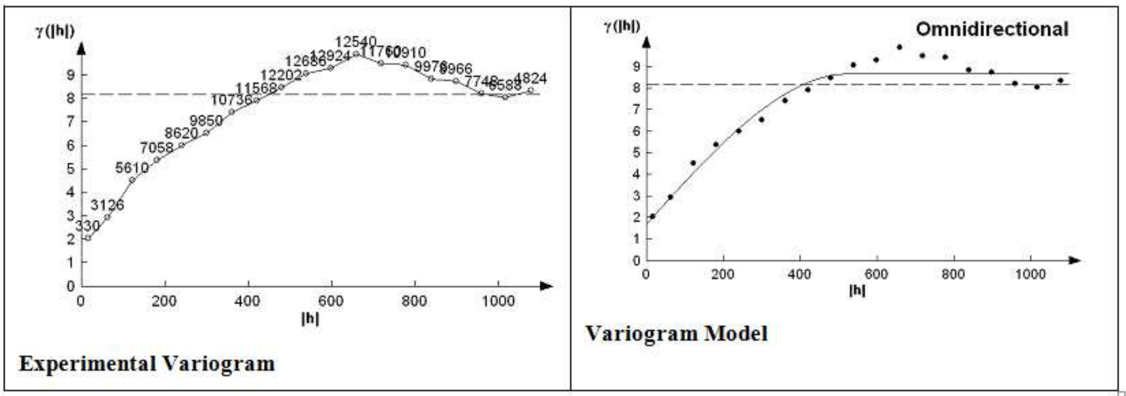

Figure 4: Variogram Analysis for Western Zone

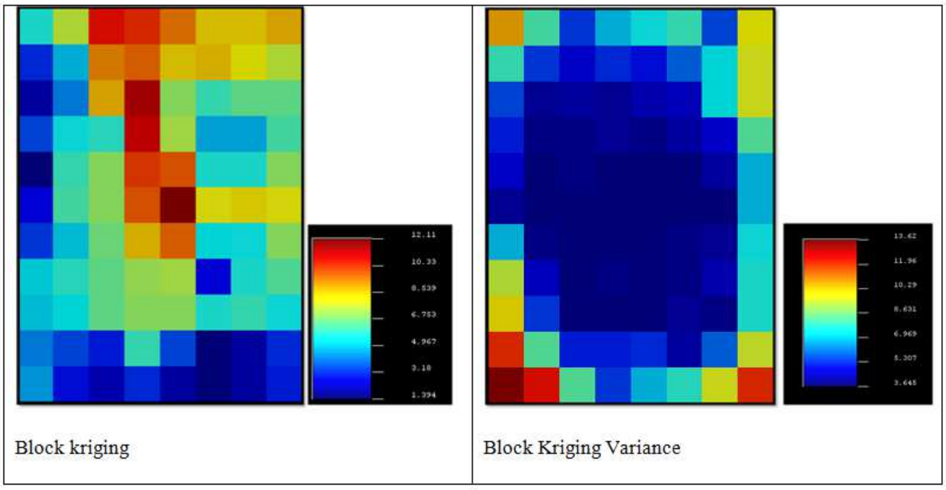

Figure 5: Kriging Analysis for Western Zone

N	Valid	818
	Missing	0
Mean		6,1032
Std. Error of Mean		0,10005
Median		6,2500
Mode		2,00
Std. Deviation		2,86152
Variance		8,188
Skewness		0,209
Std. Error of Skewness		0,085
Kurtosis		1,113
Std. Error of Kurtosis		0,171
Range		19,13
Minimum		0,10
Maximum		19,23
Sum		4992,39
COV		0,4688

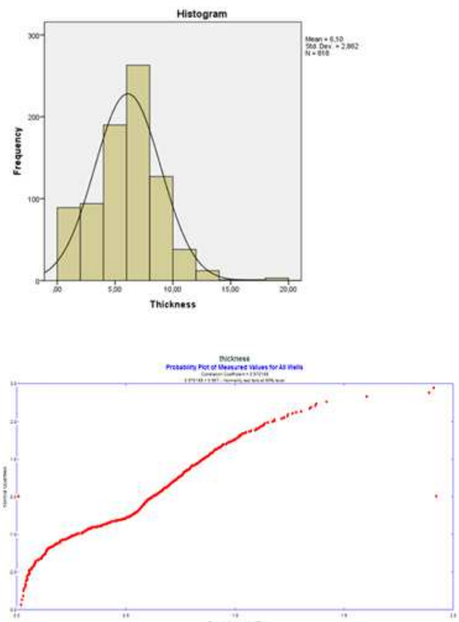

Figure 6: Basic Statistical Analysis for Eastern Zone

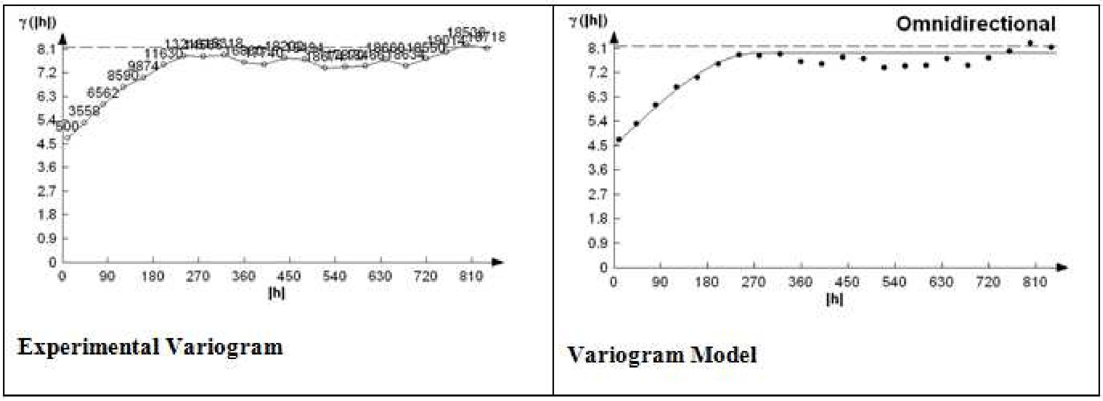

Figure 7: Variogram Analysis for Eastern Zone

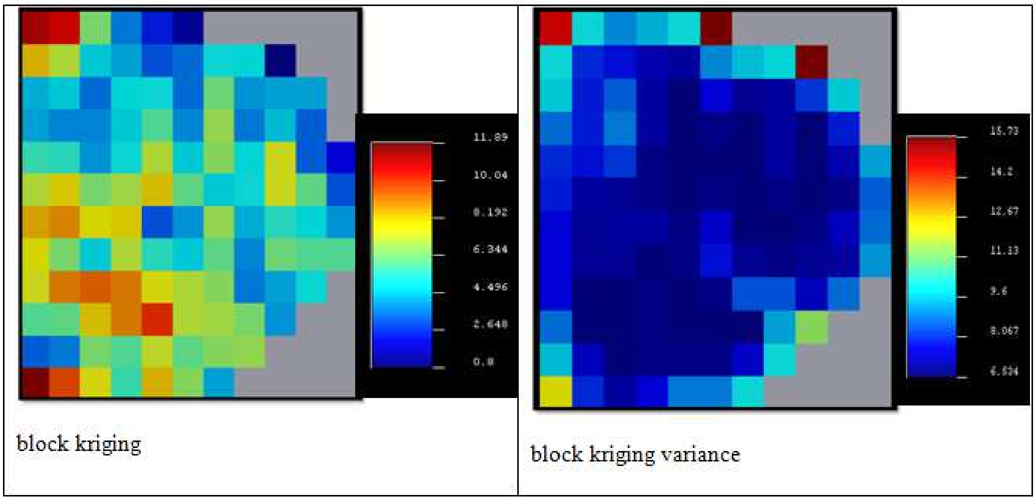

Figure 8: Kriging Analysis for Eastern Zone

CONCLUSIONS

A different result in the classification of coal resources obtained by geostatistical analysis and procedures of SNI 515, 2011 was caused by the basic assumptions that differ from the spatial characteristics in which the SNI 5015, 2011 does not consider spatial variability coal thickness and quality, while the methods of geostatistics consider spatial variability coal thickness and quality.

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