Comparison between moving windows statistical method and kriging method in coal resource estimation

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Abstract. The calculation of coal resource estimation is generally done by a conventional and nonconventional method. This research uses a nonconventional method of Moving Windows Statistical (MWS) and Kriging using 3-dimensional calculation boxes area with dimensions of 100 m x 100 m, 200 m x 200 m, and 300 m x 300 m, which is processed using MWS and SGems software. The desired value is the comparison of average coal thickness value produced from basic statistics, Inverse Distance Squared (IDS), and Kriging, and also the estimation of coal resources. By using MWS, the obtained average value of coal thickness for area 100 x 100, 200 x 200, and 300 x 300 are 6.40 m, 6.24 m, and 6.03 m, respectively. From IDS the value from 100 x100 box is 6.38 m, 200 x 200 is 6.16 m, and 300 x 300 is 5.94 m, while the calculation of Kriging using SGems generates 5.77 m of coal thickness in 100 x100, 5.68 m in 200 x 200, and 5.8 m in 300 x 300. Coal resource estimations using these three different areas of the box have also been carried out, resulting 943,480 tons, 526.460 tons, and 327.450 tons of coal in 100 x 100, 200 x 200, and 300 x 300. In the comparison of the average value of coal thickness between values determined from basic statistics, IDS, and Kriging on each area it is found that the value did not change significantly but the value from the Kriging method is the most accurate because of the influence of spatial variation of data where one point with the other point influences each other.

1. Introduction
Geostatistical techniques have the potential to introduce relevant information to the classification paradigm, such as, accounting for the spatial correlation of attributes of interest or even allowing the assessment of local distributions that enable the use of meaningful probabilistic classification criteria [1,2]. A second technique based on a moving window classification applied to conditionally simulated realizations is also proposed. This addresses the problem of the scale of classification and artifact generation leading to a high-resolution classification with reduced artifacts.

The first analysis similar to what is known today as moving split window analysis was carried out by Erdős, L et al. [3]. An important technique used in the exploratory analysis of spatial data is moving-window statistics. In this technique, summary statistics of a spatial variable is determined within local neighborhoods (windows) that make up the study site. From these summary statistics, trends and anomalies in local average value and local variability can be examined [4].

The basic idea of coal resources estimation method is to divide the whole irregular mine body into a series of relative regular coal blocks [5,6], (for instance, cuboid, prism, cone and so on). In a given industrial parameter, the main process of coal resources estimation is to respectively calculate the value
of the resources for every coal block and then summarize them. For a certain coal seam, the resources information will be control by three key factors as follows: (a) average coal quality; (b) average weight or density; (c) total volume [7].

For a coal seam with a regular geometric sharp, the volume can usually be expressed by a simple mathematical formula. Therefore, with regard to the three parameters illustrated above, the last two of them are relatively simple to obtain a credible value in coal resources estimation process. Conversely, the first argument, coal quality, is most difficult to be well evaluated in a simple way. Geostatistical interpolation. Moving Windows Statistics and IDS method are just solutions to this issue. conventional coal resources estimation methods based on geometry usually need a mass of human-computer interactions and thus inconvenient to be implemented in a computer. Additionally, geo-statistical resources estimation methods which are of high efficient and precision have been well developed and convenient to make full use of the computer software technique [8,9]. However, a proper spatial variation which is pre-requisite for geostatistical technologies is hard to obtain for many geostatistical practitioners. [8,9]. On the other hand, as a typical spatial interpolation technology, inverse distance weighting (IDW) method of which the basic character is between geo-statistical and conventional methods is easy to be understood and convenient to be implemented in computer software. Compared with geostatistical methods, a severe deficiency in this method is that the error of IDW estimates is hard to be measured and evaluated [10].

There are various moving window statistics that may be applied to investigate mineral and coal resources estimation [11,12]. In several studies, it was obtained large scale modeling, moving windows statistics methods are commonly applied to calculate local means and proportions to tren model [13]. Moving Windows Statistical and Kriging are estimation methods, and one of which is used to calculate the average value of coal seam thickness. The calculation is intended to see the average value due to the spatial effect of data. The spatial effect on the calculated data will affect the estimation result on the calculation of its coal resources. In this study, the researchers want to see the comparison of Kriging’s estimation result with Moving Windows Statistical, which can be used as an input for exploration companies to estimate more precise coal resources.

2. Moving windows statistical

Varioigraphy can detect spatial dependencies. What it does not detect is whether or not these dependencies are uniform throughout the whole research area. There could be large regional differences and in that case, variogram would not be representative of the entire area and it only provides information about the spatial variability of our data [14].

The simple method of “moving windows”-statistics can be used. A "window" of defined size and shape is moved over the data, the moving distance is equal to the width of the window. All data located within the window section are statistically summarized: the number and average of all points inside the window, the minimum / maximum values, the standard deviation, the coefficient of variation, etc. The results are again points, the centers of the moving windows and as their attributes the statistical indicators of these windows. In the case of sparse data, the window is only moved by one half of the window width to obtain more data to calculate, that equals to moving a window with overlap [15].

Moving windows statistical is the average statistical calculation method in which the data to be calculated on average in the dimensions of the box subdivided again in the smaller box area. The boxes will move vertically and horizontally in the movement to calculate the average of the desired data. In Moving Windows Statistical there is movement in the form of boxes and circle shapes. By using Windows Moving method, the calculation of coal thickness and Inverse Distance Square (IDS) is calculated. The prediction at each point in the study area can be mapped sequentially as the window moves through the study area (Figure 1).
The MVS model is automatically estimated for each neighborhood as the software interpolation moves through all the location points. When the data is nonstationary, you can estimate a heterogeneous semivariogram. In other words, use a moving window centered on the location to be predicted and create a semivariogram for each local neighborhood.

3. Basic statistics
The average is a value that represents a set or a group of data. The average value lies in the middle of a group of data organized according to the size of the value [18].

Formula:
\[
\bar{x} = \frac{\Sigma x}{N}
\]

where \(\bar{x}\) is the average, \(\Sigma x\) is the sum of all values, and \(N\) is the number of data.

Inverse Distance Square Method (IDS) is a simple deterministic method by considering the points around it. This IDS method has a distance area of the points to be calculated. The weight will change linearly according to the distance to the sample data. This weight will not be affected by the location of the sample data.

\[
\bar{x} = \sum_{i=1}^{n} \frac{x_i}{d_i^2}
\]

Information:
- \(x_i\) = Content
- \(d_i\) = Distance

Geostatistical techniques, originally developed for use in mining [19], can be used for both continuous and discrete variables, and require less stringent assumptions of stationarity compared with spatial autocorrelation techniques. In geostatistics, spatial dependence can be analyzed directionally or omnidirectionally and represented as semivariogram or correlogram. Semivariogram calculates semivariance against each lag distance (a vector \(h\)), in which semivariance is defined as half of the mean squared difference between all point pairs (\(p, p+h\)) separated by \(h\). In a correlogram, the linear (Pearson’s) correlation coefficients between point pairs separated by a vector \(h\) are plotted against vector \(h\), or lag distance at different directions [20,21]. Variogram is a graph showing an explanation of how data are correlated with distance and value of semivariogram variation.

Kriging. Kriging is resource estimation methods that are based on the best, unbiased, linear, estimator (BLUE) [22,23]. Calculation of resource estimation by kriging method can be done with a mathematical formula which is described as follows:

\[
Y = \sum_{i=1}^{n} Y_i \times W_i
\]

Information:
- \(Y_i\) = Y value at point \(i\)
- \(Y\) = Weight of point \(i\) against \(Y_i\)
4. Research methodology
The research sites are located in Sagatta District, East Kutai Regency, East Kalimantan. The sample data is the coal seam thickness of Balikpapan Formation in Sangata which was obtained from PT. Kaltim Prima Coal. Coal thickness data is taken based on drill log data.

A typical coal seam and the associated exploration engineering consisted of 1220 drill samples are selected for the test. Descriptive method is intended to describe a state or phenomenon as it is. In this research, the descriptive method is done by researching the data of the drill hole, namely lithology, and coal thickness data [24]. The descriptive statistics of data from exploration results are reviewed using MWS software, then the experimental variogram using Variowin software is made by taking the value of lag spacing and lag tolerance. Next, a valid variogram model is made by adjusting the range, sill and nugget effect values in the experimental variogram. The results of the variogram will then be estimated using Ordinary Kriging method with SGeMS software to know the value of kriging variance. Subsequently, the estimation result of coal resource is classified based on Relative Kriging Standard Deviation (RKSD) methodologies and variogram saturation on coating coal thickness [25,26].

5. Result and discussion
Based on the data of coal seam thickness used, the obtained descriptive statistical results can be seen in the table below. The obtained average coal thickness is 6.23 meters from 1220 coal thickness data. The result of the coefficient of variation of 0.31 indicates that the spread of coal thickness in the data tends to be the same (less varied). The basic statistical results can be seen in the table below.

Table 1. Basic statistics of coal thickness.

| Statistic            | Value  |
|----------------------|--------|
| Mean                 | 6.23   |
| Median               | 6.49   |
| Modus                | 5.9    |
| Deviation Standard   | 2.724  |
| Variance             | 7.422  |
| Kurtosis             | -0.025 |
| Skewness             | -0.13  |
| Maximum              | 0.10   |
| Minimum              | 14.54  |
| Sum                  | 7601.75|
| Count                | 1220   |
| Coef of Variation    | 0.31   |

From the results of basic statistical calculations, the data shows the normal population with CoV 0.31, then the calculation is performed using Moving Windows Statistical (MWS) and Kriging.

Table 2. The output of calculation using MWS.

| Sample | Mean (m) | Variance (m²) | Coef of Variation |
|--------|----------|---------------|-------------------|
| 1      | 96       | 194.200       | 0.15              |
| 2      | 98       | 194.200       | 0.46              |
| 3      | 99       | 194.200       | 1.25              |
| 4      | 100      | 194.200       | 7.83              |
| 5      | 101      | 194.200       | 9.05              |
| 6      | 102      | 194.200       | 11.29             |
| 7      | 162      | 194.200       | 12.22             |
| 8      | 163      | 194.250       | 11.31             |
| 9      | 164      | 194.250       | 7.54              |
| 10     | 165      | 194.250       | 6.79              |
| 11     | 166      | 194.250       | 7.79              |
| 12     | 167      | 194.250       | 8.32              |

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The calculation of average coal thickness and inverse distance square with moving windows statistical method and calculation with kriging can be seen in table 2 below.

**Table 3. Average calculation results, IDS and Kriging.**

| No | Block Area     | Mean IDS | Kriging |
|----|----------------|----------|---------|
| 1  | 100 m x 100 m  | 6.40     | 5.77    |
| 2  | 200 m x 200 m  | 6.24     | 5.68    |
| 3  | 300 m x 300 m  | 6.03     | 5.80    |

The calculation results of the average thickness of coal with both methods show that the result from kriging is better. This is due to the influence of spatial data, namely the influence of space on the calculation of the average.

**Figure 2.** Variogram model of seam coal thickness.

After variogram modeling is done (Figure 2), the obtained sill value is 3.975, nugget effect 3.6 and range 520.

**Figure 3.** (a) Calculation Result of Kriging Block Coal Seam thickness with block dimension of 100mx100m (b) Calculation Results of Kriging Variance of Coal Seam Thickness.

The calculations of resource estimation on the dimensions of area 100 m x100 m, 200 m x200 m, and 300 m x300 m are then performed by Kriging (Figure 3). The calculation results are provided in table 4 below.

**Table 4.** Estimation of coal resource estimates.

| Block Area    | 100 m x 100 m | 200 m x 200 m | 300 m x 300 m |
|---------------|---------------|---------------|---------------|
| **Measure Coal Resources** | 6.936.938     | 5.092.680     | 4.760.577     |
| **Indicated Coal Resources** | 31.212.067    | 36.690.154    | 35.369.436    |
| **Inferred Coal Resources** | 10.751.150    | 16.026.352    | 19.534.141    |
| **Total**     | 48.900.156    | 57.809.187    | 59.664.156    |
6. Discussion
In MWS, the calculation of the mean value will be more detailed if the area of the box is smaller (100 m x 100 m). If compared to MWS and Kriging calculations, the value of the thickness of the coal seam produced by Kriging is smaller, but the difference between the two methods is not too large. The resulting deviation is relatively small. But the results of Kriging are closer to reality because in their calculations using a weighting factor. Furthermore, to calculate coal resources, it will be better to use the Kriging method (RKSD).

7. Conclusion
From the research results the conclusions can be drawn as below:

- The value of the comparison between the value of x, IDS, and Kriging for coal thickness in the different areas as follows:
  \[ X = 6.22 \text{ m}, \quad \text{IDS} = 6.16 \text{ m}, \quad \text{Kriging} = 5.75 \text{ m}. \]
  The difference in mean yield of thickness is not significant, but the kriging result is more accurate because it takes into consideration spatial variation so that the calculation results of resource estimation will be affected.
- The Relative Kriging Standard Deviation (RKSD) method is better at classifying and estimating coal resources with the estimated resource: For 100 m x 100 m = 48,900,156 tons, n For 200 m x 200 m = 57,809,187 tons and For 300 m x 300 m = 59,664,156 tons

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