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Bauxite Resource Estimation Analysis Using Ordinary Kriging and Inverse Distance Weighting in West Kalimantan

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Abstract
A mining company engaged in bauxite mining which is located in Nanga Tayap District, Ketapang Regency, West Kalimantan Province. Currently, the company is carrying out further exploration activities to find potential bauxite resources which will later be upgraded into reserves for mining. In resource estimation, several methods can be used, such as the Nearest Neighbor Point method, Inverse Distance Weighting, and Ordinary Kriging. This research aims to analyze two resource estimation methods, namely Inverse Distance Weighting and Ordinary Kriging for resource estimation and choose the best method based on geological conditions and RMSE value parameters. Based on the results of this research, the estimated value of bauxite resources using the IDW method obtained a tonnage of 1,046,874.99 tons with an average Al_2O_3 content of 47.28%. Meanwhile, the estimated bauxite resource value using the OK method obtained a tonnage of 1,046,875.01 tones with an average Al_2O_3 content of 48.15%. Based on the calculation of the Root Mean Squared Error (RMSE) value from the two methods, the respective RMSE values were obtained, namely IDW = 0.0001263 and OK = 0.0084145. From these results, it can be concluded that the best method for estimating bauxite resources in the Enggang block is the Inverse Distance Weighting (IDW) method.

1. Introduction

A mining company operating in the bauxite mining sector which is currently still carrying out mining exploration activities. The mining block is divided into several blocks, including the Teluk Keramat Block, Bukit Tunggal Block, Enggang Block, and several other blocks. The block that will be estimated in this research is the Enggang Block which has an area of 30 Ha and has a total of 89 drill hole points with a spacing between test pit points of 50 meters.

Resource estimation generally uses geostatistical methods in the mining industry [8], one of which is the bauxite mining industry. Estimation of bauxite resources can be done using several geostatistical methods, including Ordinary Kriging (OK), Nearest Neighbor Point (NNP), and Inverse Distance Weighting (IDW). This research is one of the activities carried out to analyze or make a comparison between the Ordinary Kriging (OK) technique and the Inverse Distance Weighting (IDW) technique in estimating bauxite resources in Ketapang Regency, West Kalimantan Province using Micromine 2020 Software.

Resource estimation using the Inverse Distance Weighting (IDW) method is an estimation method that takes into account the relationship between spatial location (distance), which is a linear combination or weighted average price of data points in the surroundings [15]. Meanwhile, the Ordinary Kriging (OK) method is a geostatistical interpolation technique used in the mining industry to interpolate input data using block models [8]. Ordinary Kriging requires variogram modeling before the estimation process and provides the Kriging variance value as an index of data configuration [1].

According to the third edition of the SME Mining Engineering Handbook, there is a basis for selecting an estimation method based on deposit geometry and the coefficient of variance value. Bauxite is included in medium geometry with a uniform grade, but with an uncertain thickness. Several methods can be used to estimate sediment geometry conditions as mentioned above, including Ordinary Kriging and Inverse Distance Weighting depending on the value of the Coefficient of Variance obtained [6].

Apart from mapping the distribution of ore and grade distribution to enable resource estimation, another aim of applying the Ordinary Kriging and Inverse Distance Weighting methods is to compare the performance of each method for each variable being estimated. The method with the smallest Root Mean Square Error (RMSE) value is then considered the best method [16].

2. Methodology

This research was carried out using a quantitative method consisting of 4 stages to calculate bauxite resource estimates, which will later determine the best estimation method of the two methods, adjusted to geological conditions, deposit geometry, and the value of the coefficient of variance.

2.1. Preparatory Stages

At this stage, it is carried out by searching and then studying literature related to bauxite mining, related resource estimation methods, updated laws and regulations, data from previous research, and sources from books, journals, and company archives.

2.2. Stages of Data Collection

This stage is carried out by looking for supporting data, both primary data and secondary data. The data obtained are mostly obtained from the company, namely regional geological conditions, test pit and drill hole data, assay data (grade Al_2O_3), and exploration mining activity plans contained in feasibility study documents and exploration documents.

2.3. Stages of Research in the Field

This stage was carried out field observations at quartz sand mines in the Riau Islands. Then determine the boundaries of the area to be studied for reclamation plans, especially the reclamation of the production operation stage.

2.4. Stages of Final Report Preparation

This stage is carried out by making a reclamation plan map, reclamation planning according to the state of the region, calculating the costs of the reclamation plan and drawing conclusions and suggestions from research that has been prepared.

3. Results and discussions

3.1. Assay Data

Assay data is data that contains the drill point code, sample code, as well as the depth (from to) and the grade for each depth of grade for each sample code at one drill point. The assay data contains bauxite content data with a minimum content of 30.31% and an average content of 47.97% with the largest thickness of the sample ID being 2.90 meters while the smallest is 0.4 meters.

3.2. Collar Data

Collar data is data that contains the coordinates (x, y, and z) of the drill point along with the drill depth. Collar data aims to describe the location of the drill point. The minimum depth in the drill hole is 2.2 meters while the deepest is 13.70 meters with an average depth of 4.78 meters.

3.3. Lithology Data

Lithology data is data that contains the thickness (from to) of each rock layer (lithology). Lithology data aims to describe the lithology of each sample drill point. In the lithological data, there are several bauxite layers with the thinnest thickness being 0.4 meters and the thickest being 2.4 meters.

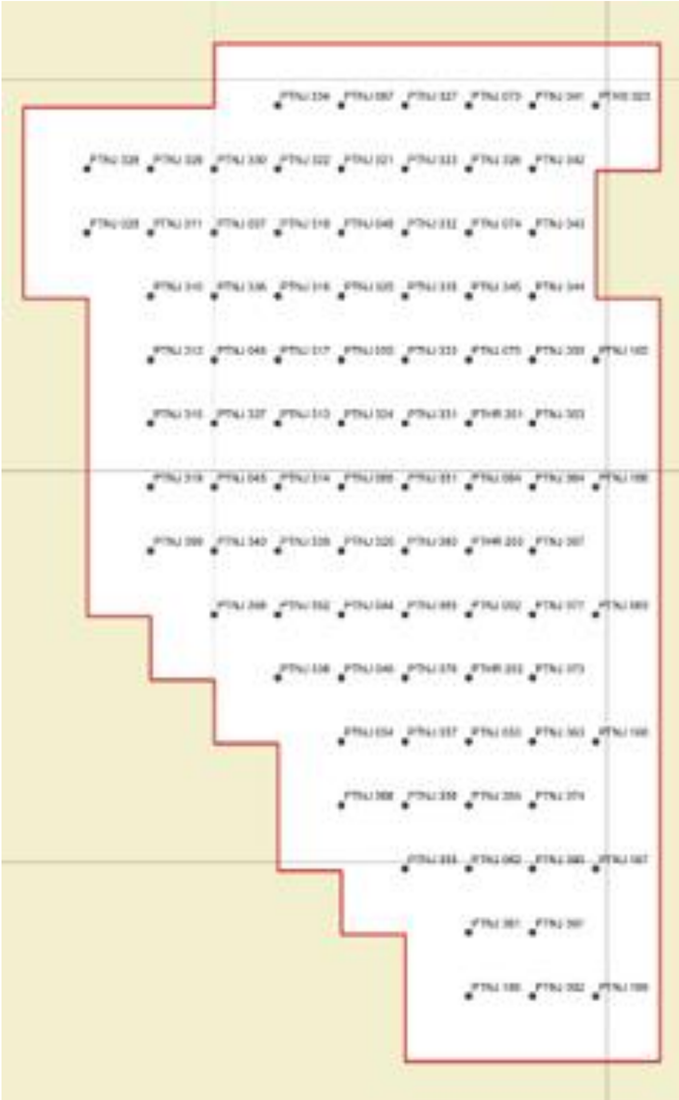

Figure 1. Drill Point Distribution

3.4. Survey Data

Survey data contains the dip direction and azimuth of the drill point. The survey data aims to describe the slope of the drill point. All drill holes have a dip value of -90 and an azimuth of 0. This indicates that the drill hole is perpendicular to the bottom.

In this research, there were 89 drill holes in an area of ± 30 Hectares. The database was created using collar data, assay data, survey data, and lithology data. The distribution of drill holes is depicted in Figure 1.

Statistical parameter calculations were carried out on the database using Micromine 2021.5 software in the ore zone. So the results obtained are as in table 1.

Table 1. Statistical analysis of Al_2O_3 content data

Variabel	*Min*	*Max*	*Count*	*Mean*	*Var*	*Std Dev*	*Cov*	*Skew*
Grade Al_2O_3	30,31	57,98	208	47,97	28,25	5,31	0,11	-0,20

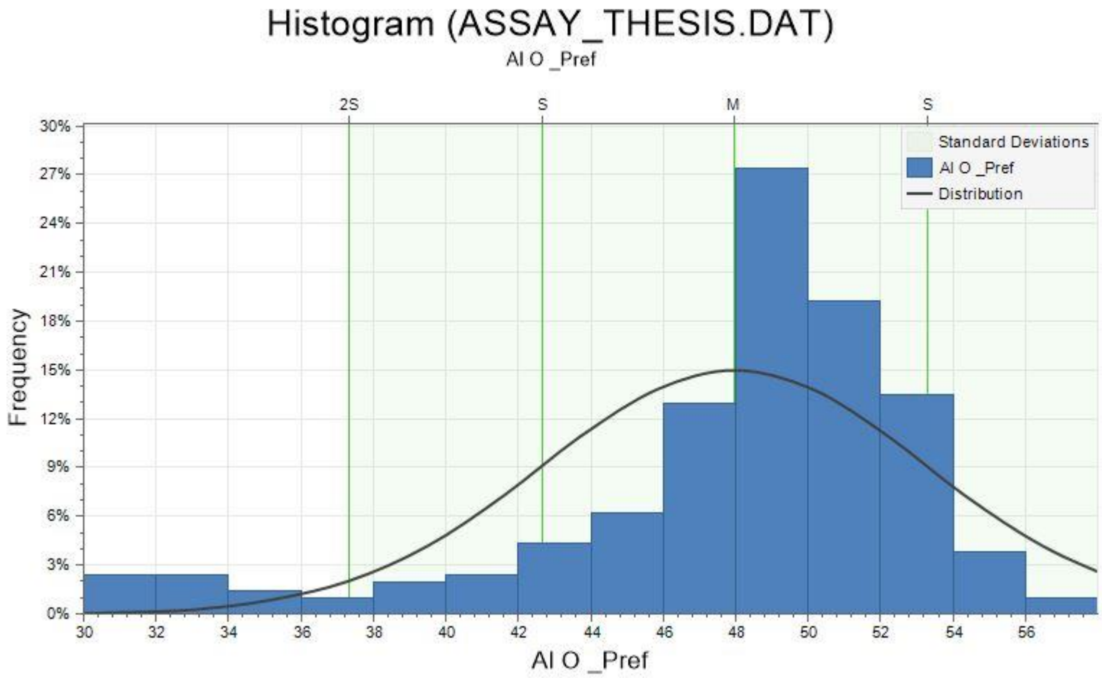

Figure 2. Assay Data Histogram

Calculation of the weighted average grade is necessary before assessing bauxite resources to obtain the average grade at a drill point per meter. Mathematically, the calculation of the weighted average grade is carried out using the Micromine 2021.5 software which composites the grade at one drill point per 1 meter.

Data distribution analysis for these variables was also carried out using a histogram created using Micromine 2021 software. The histogram does not show the presence of outlier or outlier data, so determining whether the data variable needs verification or not. Based on the CV data, the histogram shows data with a negative skewness value, which means that the data distribution tends to be skewed to the right, so that the data distribution is mostly in higher data, but the average value is 47.72, which is not a striking difference with the median value, namely 49.08 which shows that the data variation is not too high. The skewness value can indicate normal data when the value has a range between -2 to 2, based on this it can be concluded that the data from this variable has a normal distribution (see Figure 2).

Statistical analysis calculations were carried out on the weighted average level data to determine the characteristics of the collar data used in this study. Mathematically, statistical analysis was carried out on the Al_2O_3 content in the bauxite ore layer. Statistical analysis activities were carried out using Micromine 2021.5 software, the results of the analysis are shown in Table 2. below:

Table 2. Statistical Parameters on Weighted Average Levels

Variabel	***Min***	***Max***	***Count***	***Mean***	***Var***	***Std Dev***	***Cov***	***Skew***
Kadar Al_2O_3	30,31	57,98	282	47,72	34,14	5,84	0,12	-0,23

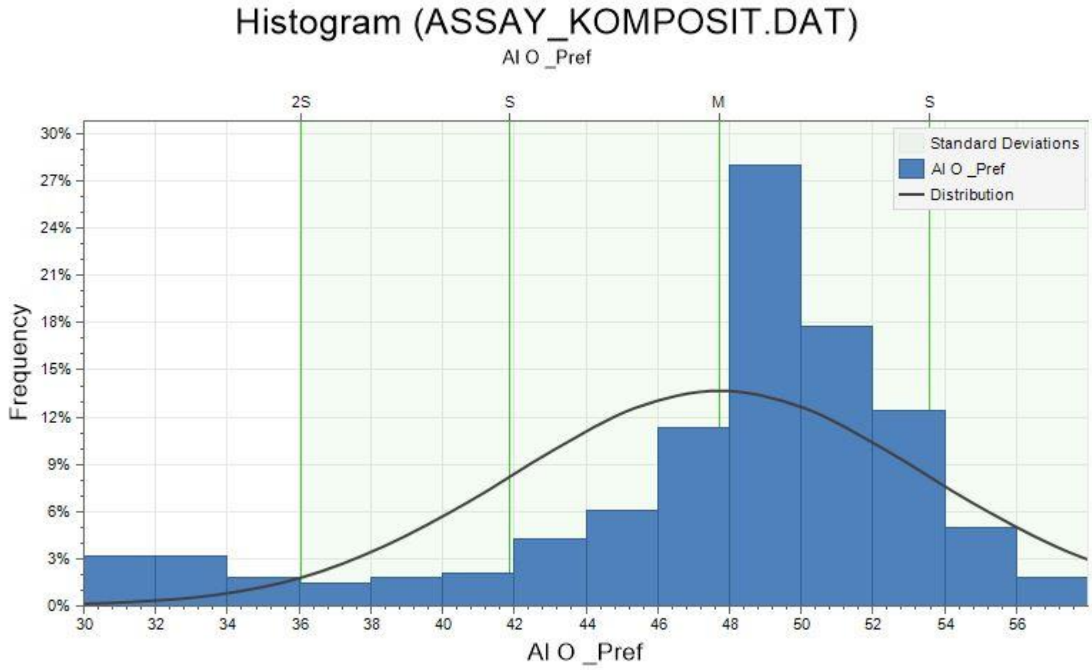

Figure 3. Assay Composite Data Histogram

3.5. Variogram Study

The variogram study is a variogram analysis carried out by matching (fitting) the experimental variogram with the theoretical variogram using the Micromine 2021.5 software using the bauxite composite database in the ore layer. The variogram models include spherical, exponential, and Gaussian models. The variogram study in this research was carried out with only one variogram model, namely the spherical model used in this study because it is considered a suitable model for mineral deposits.

3.6. Application of OK and IDW Methods in Resource Modelling

a) Block Model Dimension

The dimensions of the block model are very important in estimating with 3D (three-dimensional) shapes. This is because the shape of the block which resembles a beam aims to represent mineral deposits in a certain location. The dimensions of the model block must be length, width and thickness. In general, the length of the block model is expected to represent one drill point. The thickness is adjusted to the length of the weighted average grade. Determining the area limits for the entire block model requires considering the location of each drill point. The area limits on the block model can be seen in Figure 4.

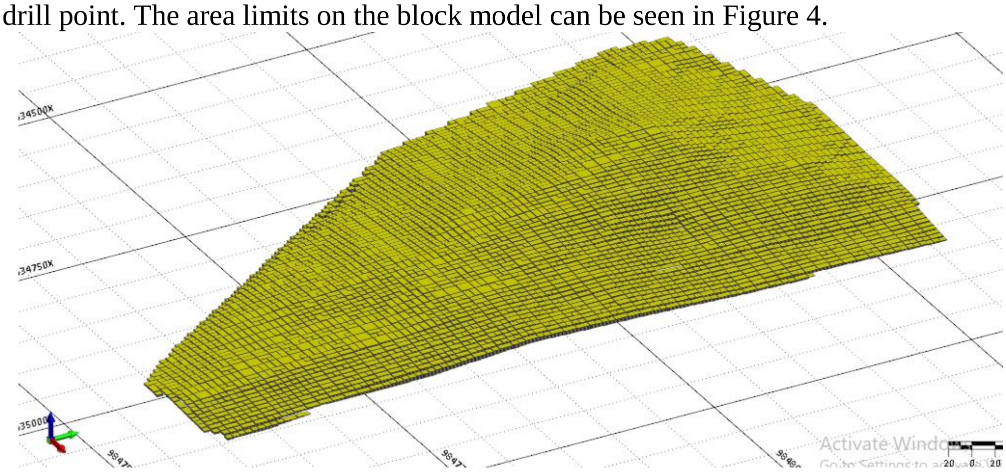

Figure 4. Block model area

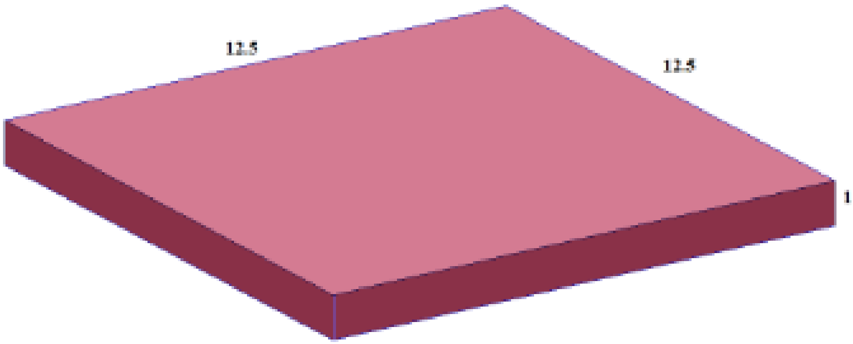

Figure 5. Block Model Dimension

In this research, the distance between drill points is 50 m, so that the block model dimensions are 12.5 m long, 12.5 m wide and 1 m thick as in Figure 5.

b) Geological Modelling

A geological model is a form of appearance in the field that is illustrated through lithological data. Lithological data itself contains information about the rock layers located at a drill point. Lithological data functions to limit rock layers so that they do not exceed boundaries. In this research, the layer for which geological modeling was made was only the bauxite ore layer. The geological model is as follows:

3.7. Result of Resource Estimation

a) Inverse Distance Weighting (IDW) Method Estimation Results

After creating a geological modeling of the form of Bauxite Ore and creating a model block from the geological model, a resource estimate calculation was carried out using the Inverse Distance Weighting (IDW) method. Estimations using this method are carried out using power values of 1, 2, 3, 4, and 5.

Figure 6. Geological Model Form of Bauxite Ore

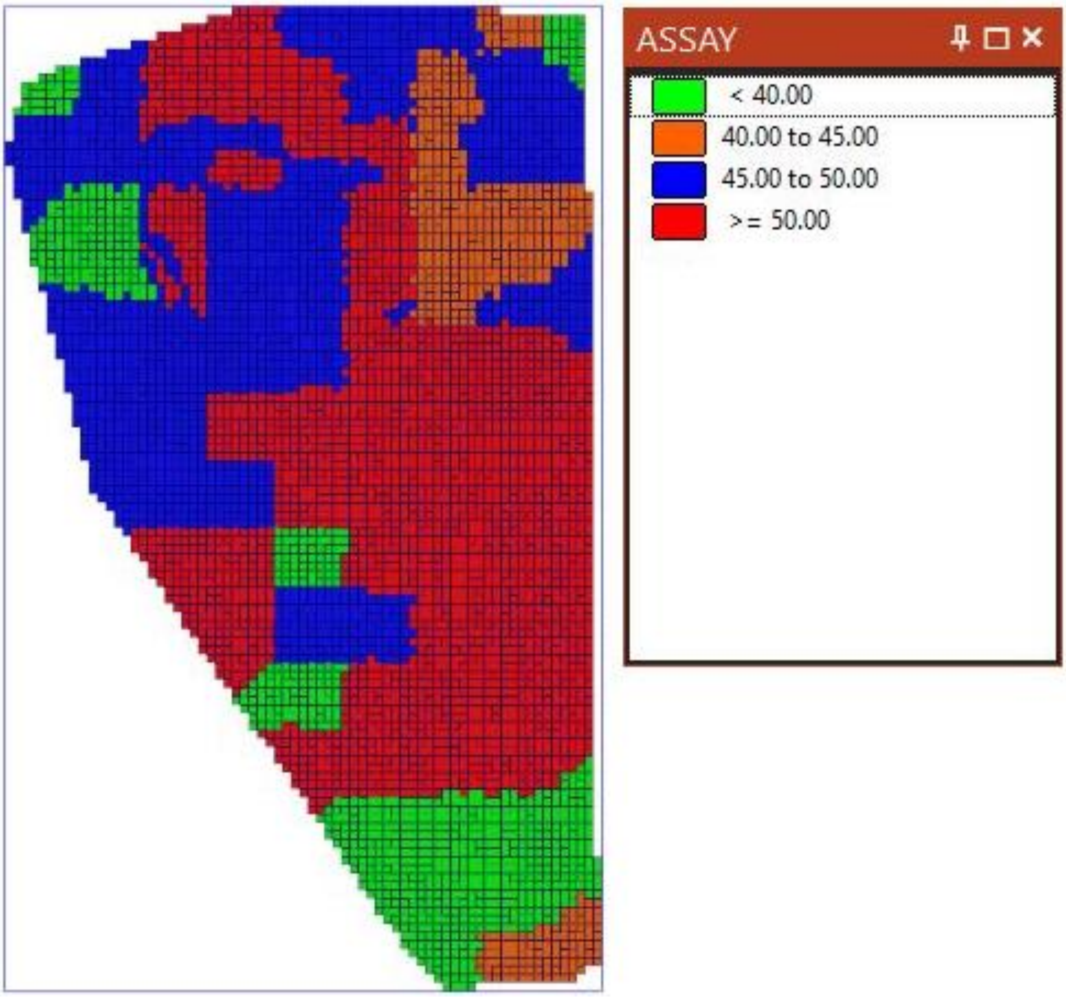

Figure 7. Bauxite Ore Estimation Results Using the IDW Method

Estimation of Al_2O_3 content in the bauxite ore zone using the Inverse Distance Weighting method using a power value of 2 as in the following Figure 7.

The results of the bauxite ore assessment using the Inverse Distance Weighting method with a power value of 2, obtained the amount of resources and average grade in Table 3. following:

Table 3. Results of Bauxite Resources Using the IDW Method

Grade Interval	Volume (m^3)	Density (t/m^3)	Tonnage (Ton)	Average Grade Al_2O_3 (%)
<40%	88,378.91	1.6	141,406.26	35.04
40%-45%	52,597.66	1.6	84,156.26	42.56
45%-50%	219,453.13	1.6	351,125.01	48.02
>50%	293,867.19	1.6	470,187.50	52.20
Total	**654,296.87**	**1.6**	**1,046,874.99**	**47.28**

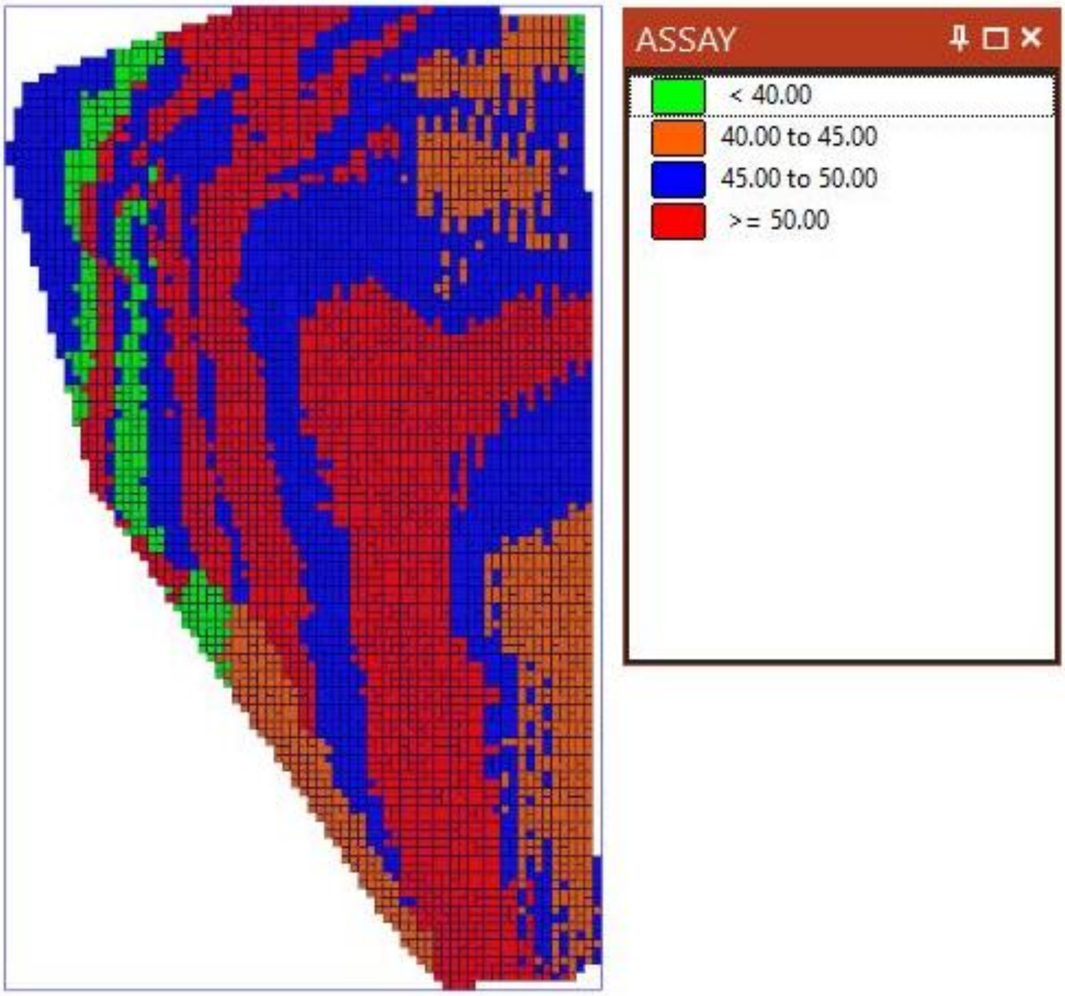

Figure 8. Bauxite Ore Estimation Results Using the OK Method

b) Ordinary Kriging (OK) Method Estimation Results
After obtaining the variogram parameters from the variogram fitting results, it was found that the spherical variogram model was the best method in the bauxite ore zone. Then the results are input into the assessment using the Ordinary Kriging method using Micromine 2021.5 software. The results of the assessment of the bauxite ore zone using the OK method are in the following figure:
The results of the Ordinary Kriging method assessment are obtained with the number of resources and average levels in table 5.9. following:

Table 4. Results of Bauxite Resources Using the OK Method

Grade Interval	Volume (m^3)	Density (t/m^3)	Tonnage (Ton)	Average Grade Al_2O_3 (%)
<40%	36,855.47	1.6	58,968.75	36.40
40%-45%	85,175.78	1.6	136,281.25	42.52
45%-50%	281,855.47	1.6	450,968.75	48.43
>50%	250,410.16	1.6	400,656.26	51.91
Total	**654,296.88**	**1.6**	**1,046,875.01**	**48.15**

No	Method	RMSE
1	IDW	0.00012629
1	OK	0.00841450

Table 5. RMSE Estimation Results

3.8. Interpolation Evaluation Results

After interpolation has been carried out using the Inverse Distance Weighting and Ordinary Kriging methods, an evaluation is needed regarding which method is the most accurate using the Root Mean Square Error (RMSE) method by comparing the estimated results with the actual results using the help of Microsoft Excel 2016 software. Interpolation evaluation is carried out employing calculating the error value that exists between the estimated results and actual drilling data. The smaller the RMSE value, the more accurate the estimation method. RMSE calculations are carried out by calculating the RMSE values from the two methods.

Based on the RMSE calculation results, it was found that the accurate estimation method for the bauxite ore zone based on each grade interval is the Inverse Distance Weighting (IDW) method.

4. Conclusion

From the results of research on the Bauxite Resources Estimation analysis with Ordinary Kriging and Inverse Distance Weighting Methods, the results of the bauxite resource assessment using the ordinary kriging method showed a total tonnage of 1,046,875.01 tones with an average grade of 48.15% Al_2O_3. Meanwhile, using the inverse distance weighting method, the total tonnage was 1,046,875.01 tons with an average content of 47.28% Al_2O_3. Based on the results of the interpolation evaluation using the RMSE method, it was found that the IDW method was the best method for estimating resources in the Enggang block with an RMSE value of 0.00012629.

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