Modeling and Resource Classification Lateritic Nickel Deposits on a Heterogeneous Block in The Haul-Sagu Area using Estimation and Simulation Geostatistical Method

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Abstract. Deposits modeling is a very important thing in the exploration field, especially in estimating reserves. This research was conducted to model the geometry of lateritic nickel ore deposition on heterogeneous blocks using the geostatistical estimation method Ordinary kriging (OK) and simulation methods namely, Sequential Gaussian Simulation (SGS) then the distribution of laterite zonation was carried out to calculate the resource and mineral resource classification based on estimation data and simulation. The estimation results using the OK method have an average value of Ni higher than the average Ni grade from the SGS simulation results. Analysis of the calculation of total tonnage of resources from the estimated OK data shows the total amount of measured tonnage of 5,875 tons is far lower than the amount of resource tonnage from the SGS simulation data which displays the total amount of tonnage measured 189,766 tons. However the average grade of Ni from measured OK Resources is 1.49% higher, compared to the average Ni grades from measured resources of SGS 1.33%. with a difference of 0.16% Ni grades. The opposite occurs when the average Fe grade of the measured OK resource is lower 24.15% compared to the average Fe grade of the Measured resource of SGS 32.81% with a very large difference in Fe grade of 8.66%. Keywords: Heterogeneous blocks, geostatistical models, laterite nickel, resource classification

1. Introduction

The existence of a mine does not begin on the first day of production, but several years before, that is when the mining company decided to start exploration activities [1]. In the field of exploration, resource modeling is a very important part of estimating reserves. From the modeling will be obtained a description of various matters relating to the minerals, including: concentration of concentration, distribution of potential, and the form of deposits. Whereas depositional geometry is related to the distribution of parameters such as topographic elevation, bore hole depth and deposition thickness.

In this study, the modeling of laterite nickel resource grade, in the Haul-sagu area (Obi Island - North Maluku), is based on drilling data with a certain spacing. This modeling relates to other parameters such as topography, geology, and the direction of distribution of minerals as has been applied in other studies [2] [3] [4] [5]. The data obtained will be analyzed by estimation and geostatistical simulation methods [6] [7] [8]. For estimation using the approach Ordinary Kriging (OK) [1] [3] [4] [9], while the simulation uses the method Sequential Gaussian Simulation (SGS) [1] [5] [6] [10]. So it will be produced grade modeling of the two methods with the aim to see the grade of difference from the application of the two methods, in the modeling of heterogeneous block laterite Nickel in the Haul-sagu region [1] [7]. The results of modeling with these two methods also continued with the division of Ni (Nickel) laterite zoning [11] [12] and calculation of reserves and classification of mineral resources [8] [12] [13] [14]. The methods in this study have been applied to minerals other than nickel deposits in other areas [2] [5] [6] [8] [10] [15].

Therefore in this research, this modeling is very important to be carried out on mining blocks that have heterogeneous Ni grade in the Haul-sagu area using both OK and SGS methods, because the results of this study are expected to provide an accurate picture of the quantity and quality of the
deposits, as well as the approximate shape/ dimensions precipitate nickel laterite blocks heterogeneous, which in turn can be used as a basic reference in the implementation of the mining method or planning mine (mine planning) right, as well as to minimize the error rate, or the difference in grade between the results of exploration and realization of mining. This research can be used as a reference to be applied to heterogeneous nickel mining blocks in other regions.

2. Methods

This research was conducted with a methodology including variogram fitting, estimation of Ordinary Kriging (OK) and simulating the model using the method Sequential Gaussian Simulation (SGS), on the values of Ni and Fe grade. Before estimating and simulating the process, the Block model is divided into blocks consisting of a Block size of cell 12.5 × 12.5 × 1 meter. size is cell Block taken from the distance of the drill spacing, where the distance dominated by the drill spacing is 50 meters (Figure 1). Before modeling, the compilation of data and composite data for Ni and Fe grade from drill data is carried out first [16] [17] [18].

![Figure 1. Map location of the drill point distribution in the Haul-Sagu research area on Obi Island](image)

2.1 Geostatistics Method

Use of kriging geostatistical methods is carried out in two stages namely, firstly the calculation of a variogram or semivariogram and covariance functions, the second step is to assess an unsampled location (Equation 1).

Where:

\[ y(h) = \frac{\sum_{i=1}^{N}[z(x_i) - z(x_i + h)]^2}{2(h)} \]  

(1)

In this study used spherical model variogram fitting in estimation and simulation.

2.1.1. Block Estimation of Ordinary Kriging Method. Is an estimation method contained in geostatistics. In this method it is assumed that the mean (mean) is unknown and is of constant value. There are several things that need to be considered in processing data with methods, ordinary kriging among others:
1. Look for the average value in all blocks. If the price of an $Z$ grade of a Block volume is estimated $\bar{Z}(V)$, the estimated grade can be calculated by weighting the grade of the sample $Z(x_i)$.

$$z(V_i) = \sum_{i=1}^{n} \lambda_i \cdot Z(x_i) \quad i = 1, 2, 3, \ldots n$$

(2)

2.1.2. Simulation Method. In this study, the simulation process is carried out with a Sequential Gaussian Simulation (SGS). The principle is that the exact simulation process for a point is the value taken from its conditional distribution from the nearest number of points. The consecutive points in the simulation are not only made from the original conditioning data around it, but also the values in the previous simulation that are around it [19] [20] [21] [22].

2.2. Mineral Resource Classification

Classification is based on the relationship between the results of Exploration, Mineral Resources and Mineral Reserves [18]. In this study, the grade of geological confidence in the classification of resources is represented by the grade of error in making a reserve estimation model, this error rate is measured by variance or error variance [8]. According to Blackwell [1], the relationship between Measured, Indicated and Inferred resources is based on the RKSD (Relative Kriging Standard Deviation) from the calculation results. Resources can be classified by the following equation (Equation 3)[13]:

\[
\text{Measured 0.3} \leq \text{Indicated 0.5} \leq \text{Inferred}
\]

\[
\frac{\text{RKSD}}{\text{σE}} = \frac{\text{Z}*}{\text{Kriging Stadard Deviation}}.
\]

\[
\frac{\text{σE}}{\text{Z}*} = \text{Kriging Value}
\]

2.3. Data

At the research site there are 12 exploration blocks which are assumed to be mining blocks with drilling spaces of 100 m, 50 m, 25 m. In this study, from a total of 12 research blocks, only 1 block was found in the north (Figure 1), so that from 1 block the estimation were carried out Ordinary Kriging and SGS simulation. The block has a total number of drill points spread out to reach 73 drill points spaced 100 m and 50 m, with the following sample grade statistics (Table 1).

| Statistical Parameters | Ni (%) | Fe (%) |
|------------------------|--------|--------|
| Number of samples      | 1186   | 1186   |
| Mean                   | 0.65   | 32.82  |
| Minimum                | 0.06   | 2.75   |
| Maximum                | 2.09   | 60.48  |
| Std. dev               | 0.39   | 17.26  |
| Sample variance        | 0.15   | 297.86 |
| CV                     | 0.61   | 0.53   |

2.3.1. Model Variogram OK. Four-way horizontal variogram of Ni and Fe grade, showing isotropic tendencies, so that the variogram in this study was used Omni-directional and then combined with the vertical directional variogram for subsequent fitting manually with two variogram structures and displaying the following parameters (Table 2)

| Element | Structure | Type Variogram | Nugget | Sill | Total Sill | Range |
|---------|-----------|----------------|--------|------|------------|-------|
| Ni %    | Vertical  | Spherical      | 0.03   | 0.121| 0.164      | 8     |
|         | Horizontal| Spherical      | 0.013  | 0.121| 0.210      |       |
| Fe %    | Vertical  | Spherical      | 0.275  | 0.121| 0.85       | 168   |
|         | Horizontal| Spherical      | 0.85   | 0.121| 168        |       |
2.3.2. Variogram Model SGS. Producing variogram is done before the simulation, i.e., variogram was made based on the data samples that have been done in advance of the normal standard of each element of the grade of Ni and Fe. The standard variogram fitting process is normally done with experimental horizontal and vertical direction variograms, the fitting process has a total sill of 1. The results of the variogram fitting model are used for the SGS simulation (Table 3).

| Table 3. Parameters of normal Standard variogram fittings Ni and Fe grade |
|----------------|---------|--------|----------|--------|-------|------|
| Element | Type variogram | Structure | Nugget Variance | Sill | Total Sill | Range |
| Ni % | Spherical | 1 | 0.03 | 0.8 | 1 | 8.5 |
| Ni % | Spherical | 2 | 0.17 | 215 |  | |
| Fe % | Spherical | 1 | 0.02 | 0.98 | 1 | 8.3 |
| Fe % | Spherical | 2 | | | | |

3. Results and Discussion

3.1. Results of Ordinary Kriging Estimation and Sequential Gaussian Simulation for Ni and Fe grade.

OK estimation results on heterogeneous blocks display the value of mean Ni 0.58% higher than the value of mean Ni 0.57% of the results of the SGS simulation with a difference of 0.01%. Whereas at the average Fe grade, the mean value of the estimated OK result of 31.13% is lower than the mean of the simulation results of SGS 32.91% with a difference of 1.78% (Table 4). From the results of the OK estimation and SGS simulation on the block model, the distribution of low-grade Ni appears on the surface of the block, while the high Fe grade appears to dominate the entire block surface (Figures 2.3 & 4).

| Table 4. Statistics of estimated OK and SGS simulation results on grade of Ni and Fe |
|----------------|---------|--------|----------|--------|-------|------|
| Statistical Parameters | OK Ni (%) | SGS Ni (%) | OK Fe (%) | SGS Fe (%) |
| N. Data | 35205 | 35205 | 35205 | 35205 |
| Mean | 0.58 | 0.57 | 31.13 | 32.91 |
| Minimum | 0.12 | 0.07 | 4.57 | 3.97 |
| Maximum | 1.67 | 2.05 | 57.91 | 58.54 |
| Std Dev | 0.22 | 0.28 | 11.73 | 8.33 |
| Variance | 0.05 | 0.08 | 137.66 | 69.38 |
| CV | 0.37 | 0.48 | 0.38 | 0.25 |

Figure 2. Results of Estimation Ordinary Kriging and Standard deviation of Ni (a) and Fe (b) grade in Block model
Figure 3. The results of the realization 10 times simulation Ni grade on the block models

Figure 4. The results of the realization 10 times simulation Fe grade on the block models

3.2. Comparison of Resource Classification Results of Ordinary Kriging Estimation and Heterogeneous Sequential Gaussian Block Simulation.

Mineral source classification in this study is only based on data from OK estimation results from OK estimation data and SGS simulation results. From the results of the classification of resources, there are three categories of resources namely Inferred, Indicated and Measured.

Classification of mineral resources from the estimated OK, resources Inferred of Ni grade, appear to dominate the entire Block surface. In the East-West cross section, it appears that the resource Inferred of Ni grade occupies the East Block and spreads to the West from the cross section. In addition, in this cross section visible Indicated and Measured resources which have accumulated in the form of pockets in the western edge and in the east section of the cross section, there are only resources Indicated. Whereas in the cross section of the South-North direction, it appears that the
resources are Inferred still scattered from the South to the North section. The presence of Indicated and Measured resources also accumulates in the northern part of the cross section (Figures 5 & 7).

Classification of resources from the SGS simulation results shows that the presence of resources Measured on the Block surface appears very little in the middle of the Block, but in the East-East cross section it appears that resources Measured occupy only the western part of the cross section and the Eastern end of the cross section in the form of spots, isolated resources. Indicated and Inferred The same thing is also relatively the case in the South-North cross section, where resources Measured appear to be visible in the East of the cross section forming spots. At the center of the cross section, the measured resources form a thin layer pattern that is isolated with the Indicated and Inferred resources (Figures 6 & 7).

In this study, the classification of mineral resources from the estimated OK and SGS simulation data, it can be stated that, almost all of the modeling blocks are dominated by Inferred resources, while the existence of Indicated and Measured resources is seen as only a few and occupy the North Block (Figure 7). However, the data from OK estimation results show that the resources are measured more dominant than the SGS simulation data.

![Figure 5. Classification of resources from OK estimation results](image1)

![Figure 6. Classification of resources from SGS simulation results](image2)

![Figure 7. Cross section of resources from OK estimation results and SGS simulation](image3)

3.3. Comparison of Resource Tabulation Data on Ordinary Kriging Estimation Results with Sequential Gaussian Simulation.

Comparison of the results of the calculation of the resources of both these methods, there is resource tonnage a Measured of SGS Simulation data is greater than 189,766 tons with a 1.33% Ni grade from the tonnage amount of Measured estimated OK 5,875 tons with a 1.49% Ni grade. Total tonnage of Indicated SGS Simulation data 221,828 tons with Ni grade of 1.08% greater than the number of tonnage Indicated from an estimated OK of 163,047 tons with Ni grade of 1.16%. However, in the Resource Inferred data the OK estimation has a total tonnage of 84,000 tons with a Ni grade of 0.97%
greater than the tonnage of the Inferred SGS Simulation data of 9,250 tons with a Ni grade of 1.04% (Tables 6 & 7).

**Table 6.** Classification of total Ni-Fe ore resources, from the estimation results OK

| Total Resource Classification | Ore Tonnage (ton) | Ni (%) | Fe (%) |
|------------------------------|-------------------|--------|--------|
| Total Measured               | 5,875             | 1.49   | 24.15  |
| Total Indicated              | 163,047           | 1.16   | 36.05  |
| Total Inferred               | 84,000            | 0.97   | 44.77  |
| Total                        | 252,922           | 1.11   | 38.67  |

**Table 7.** Classification of total Ni-Fe ore resources, from SGS simulation results

| Total Resource Classification | Ore Tonnage (ton) | Ni (%) | Fe (%) |
|------------------------------|-------------------|--------|--------|
| Total Measured               | 189,766           | 1.33   | 32.81  |
| Total Indicated              | 221,828           | 1.08   | 41.24  |
| Total Inferred               | 9,250             | 1.04   | 40.22  |
| Total                        | 420,844           | 1.19   | 37.41  |

4. Conclusion

From the results of this study, it can be concluded that:

1. Total average grade between the estimated OK Ni 0.58% with the average grade of the simulation results of the SGS Ni 0.57% which has a difference of 0.01%. Whereas on the average Fe grade, the opposite shows that the OK Fe 31.13% estimation results are smaller than the SGS Fe 32.91% simulation results with a difference of 1.78%.

2. Resource classification results from estimation data Ordinary Kriging and SGS simulation on heterogeneous blocks, displaying three categories of resources, namely: Measured, Indicated and Inferred. But of the three resources, resources Inferred dominate the surface of the block model.

3. The results of the calculation of the total tonnage of resources from the OK estimation data show the total tonnage of the measured resource classification of 5,875 tons is far lower than the amount of resource tonnage from the SGS simulation data which displays the total amount of tonnage measured 189,766 tons. However the average grade of Ni from measured OK Resources is 1.49% higher, compared to the average Ni grade from measured resources SGS 1.33%. with a difference of 0.16% Ni grade. The opposite occurs when the average Fe grade of the measured OK resource is lower 24.15% compared to the average Fe grade of the Measured resource of SGS 32.81% with a very large Fe measured difference of 8.66%. From the calculation of the total resources from the OK Estimation data results, showing the presence of a total tonnage of 420,844 tons and an average grade, Ni 1.19%, far greater than the results of the SGS simulation which showed a total tonnage of 252,922 tons and an average grade of Ni 1.11%.

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