Available online at http://proceeding.rsfpress.com/index.php/ess/index
LPPM UPN "Veteran" Yogyakarta Conference Series
Proceeding on Engineering and Science Series (ESS)
Volume 1 Number 1 (2020): 301-310

Geostatistical Modeling of Ore Grade In A Laterite Nickel Deposit

Waterman Sulistyana Bargawa, Simon Pulung Nugroho, Raden Hariyanto, Oktarian Wisnu Lusantono, Rizky Fikral Bramida

Universitas Pembangunan Nasional Veteran Yogyakarta
E-mail address: waterman.sb@upnyk.ac.id, E-mail address: simonpulung@gmail.com, E-mail address: harindri@yahoo.com, E-mail address: oktarian.lusantono@upnyk.ac.id, E-mail address: rizkyfbm@gmail.com

Abstract

Reserve modeling is one of the essential aspects of exploration activity. Reserve modeling of ore commodities has classic challenges such as grade distribution and quantity of the ore reserve. This study introduced a novel reserve modeling protocol incorporated kriging methods for nickel laterite deposits. The study parameters consist of geological modeling and statistical analytic using the ordinary kriging method and nearest neighbor polygon. This study shows that the ordinary kriging method has a conservative estimation compared to the nearest neighbor polygon. Besides, the rectangular drilling pattern is the most suitable drilling pattern for the exploration activity of this study.

Keywords: reserve modeling, nickel laterite, geostatistics, kriging

I. INTRODUCTION

Reserve modeling is an essential aspect of the mining industry for the evaluation of potential mineral deposits. The purpose of reserves modeling is to give illustration through 3D modeling, grade distribution, and estimation of quality and quantity of reserves based on mine planning (Krzemień et al., 2016). This study was conducted in the South Sulawesi, Indonesia, on nickel ore deposits. The study area is hilly with a 30 – 50 m slope that acts as a nickel ore deposit trap. Nickel ore deposits are generally found on the slope embankment between ridges and hills (Porwal et al., 2010). Nickel ore deposit in this area is a laterite type deposit that occurs from the weathering of ultramafic rocks such as peridotite and serpentinite (Putzolu et al., 2020). The bedrock consists of peridotite and serpentinite. The weathering process may cause Al and Ca levels to low, while Fe, Mg, Ni, and Co are high (Scarciglia et al., 2016.). The dissolved Ni mineral and Mg during the groundwater weathering process will form garnierite mineral $H_4(Mg, Ni)_3SiO_9$ or $H_2(Ni, Mg) SiO_4n H_2O$. Granite is commonly found in the rock cracks.

This study investigated nickel grade distribution through geostatistical methods. The investigated nickel grade is divided into two categories, low grade (1.9 – 2.3% Ni) and high grade (>2.3% Ni). The final result of this study is a 3D model of ore reserves estimation.

DOI: https://doi.org/10.31098/ess.v1i1.123

II. LITERATURE REVIEW

Resources estimation methods are investigated in various studies (Bargawa, 2016; Zulkarnain and Bargawa, 2018; Yuan et al., 2020; Bargawa and Tobing, 2020). Based on those study, there are generally two methods which suitable for nickel laterite deposit; nearest neighbor polygon (NNP) and inverse distance (ID) (Ramesh et al., 2005). The geostatistical method also has capabilities for estimation in the nickel laterite deposit (Ilyas et al., 2016). Variographic studies are used for evaluating the spatial correlation between nickel grade (Jiang & Zhu, 2017).

Resource estimation models in this study are derived from the geological model, such as core drilling, which contains essays and composite (Ding et al., 2019). Geostatistical methods used in the model for spatial analysis for interpretation of general nickel deposit characteristics such as grade and composite. This study's modeling uses block model principles through kriging variances (Guo & Dias, 2020). Geological conditions and topographic are used as limitations for the estimation of nickel reserves (Hadji et al., 2013).

III. RESEARCH METHODOLOGY

This study's research methodology consists of data validation, geological modeling, topographic modeling, statistical analysis, and reserves modeling. The research methodology is shown in Figure 1.

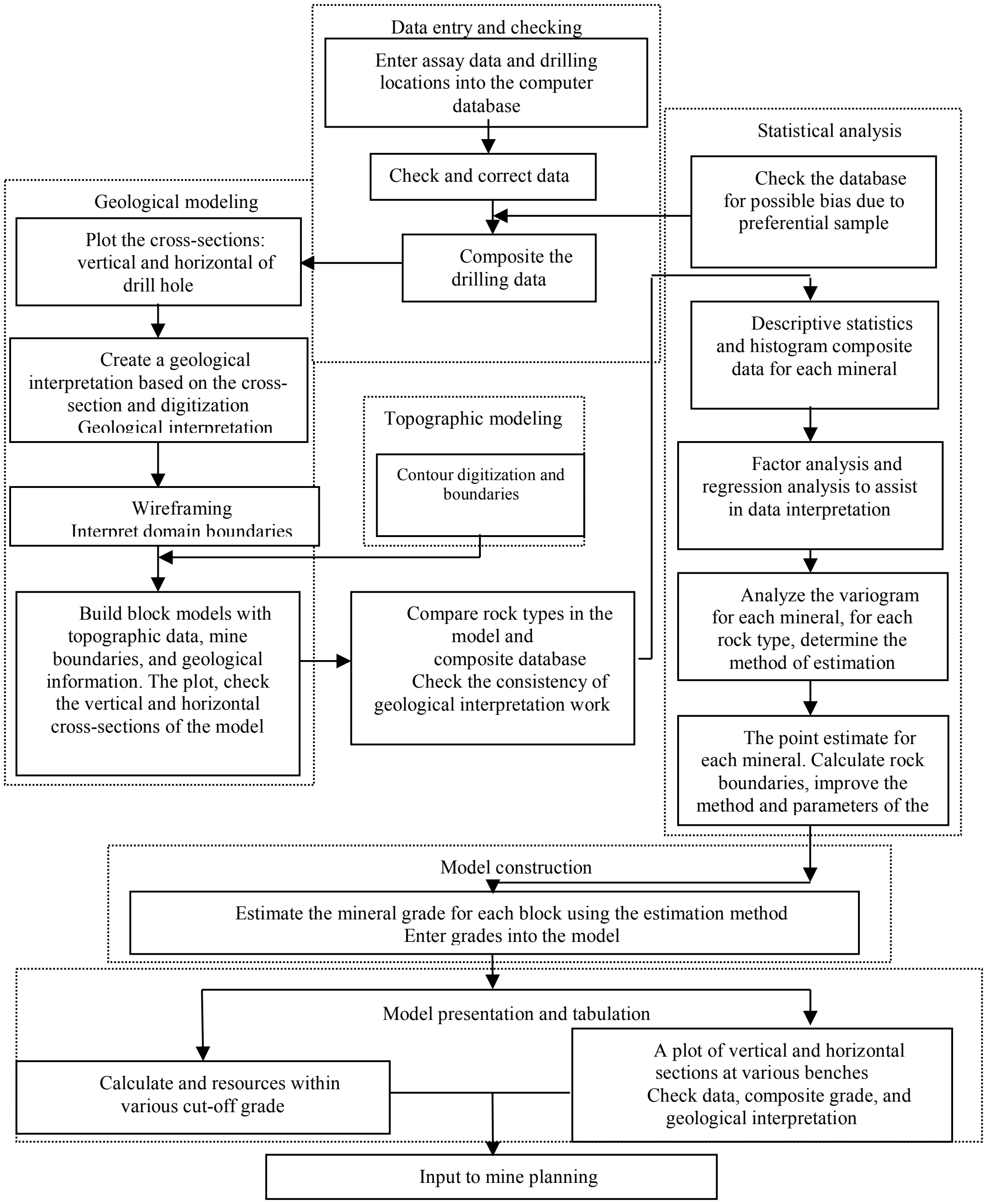

Figure 1. Research flowchart

III.1. Data input and validation

Data input for this modeling is drilling data with several variables such as assay, collar, survey, and density. The effectiveness of drilling patterns based on spatial statistical analysis will be discussed.

III.2. Statistical Analysis

Univariate statistical analysis was used to calculate nickel grade—the statistical analysis result displayed in a histogram. The data distribution was determined based on the histogram for data interpretation in general.

III.3. Geological and Topographic Modeling

The geological model is used for ore reserves limitation from being extrapolation outsize the mineralized blocks. The topographic model is also used in the ore reserves limitation through digitization in the study area. The interpretation of the topography model is carried using the software.

III.4. Block Modeling

Block modeling in this study started with a wireframe process. Wireframe of block modeling constructed from a three-dimensional framework of certain polygons. The wireframe is constructed in many ways for interpretation between domain boundaries and polygons (Coombes, 2008). The 10 x 10 x block volume is equal to wireframing volume. The block model of this study is generated from a block with a size of 1 m

The polygon method of wireframing is a basic concept of modeling. It illustrates mineral deposits characteristics in a certain area based on a certain point. The area of influence volume is estimated using equation 1 (Coombes, 2008).

$$V = A \, x \, T \qquad (1)$$

where:
V = Volume of Area of Influence (m^3)
A = Area of Influence (m^2)
T = Ore thickness (m)

III.5. Grade Estimation

The grade estimation in this study is using the ordinary kriging (OK) method. A variographic study was conducted prior to reserve estimation. The variographic study was conducted based on assay data to determine the spatial correlation between samples. The spatial correlation may indicate a correction of direction and distance of nickel grade distribution in the model. The estimation of block grade uses the following formula:

$$Z^* = \sum_i w_i z_i \qquad i = 1, ...n \qquad (2)$$

Weight (w_i) is solved using the OK formula as follows:

$$\sum_{i=1}^{n} w_j . \sigma_{ij} - \mu = \sigma_{01} \qquad (3)$$

$$\sum_i w_i = 1 \qquad (4)$$

Remarks:
σ_{ij} : sample and sample covariance
σ_{01} : block and sample covariance

III.6. Reserve Estimation

Reserves estimation was performed through reserve modeling with geological and topographical constraints. The reserves tonnage is estimated through the multiplication of block volume and density.

IV. FINDING AND DISCUSSION

IV.1. Data input and validation

The number of drill holes inputted is 261 holes, with the distance between borehole is 12.5 m. The input variable from drill hole data includes assay, collar, survey, and density of 1.92 t/m^3. The drill hole location is shown in Figure 2.

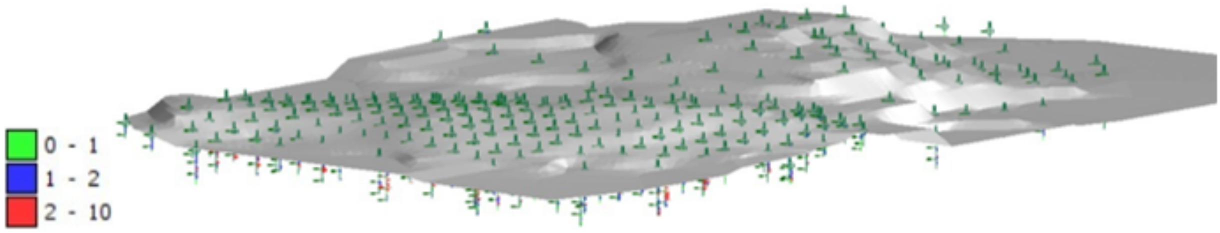

Figure 2. Drill hole location

IV.2. Statistical Analysis

The statistical analysis result is shown in Table 1. The nickel assay histogram is shown in Figure 3.

Table 1. Statistical Analysis Result

No.	Statistical parameters	Value
1	Mean	1.043
2	Standard Error	0.008
3	Median	0.907
4	Mode	0.270
5	standard deviation	0.705
6	Sample Variance	0.497
7	Kurtosis	7.194
8	Skewness	2.075
9	Range	6.483
10	Minimum	0.046
11	Maximum	6.529
12	Sum	7832.080
13	Count	7508

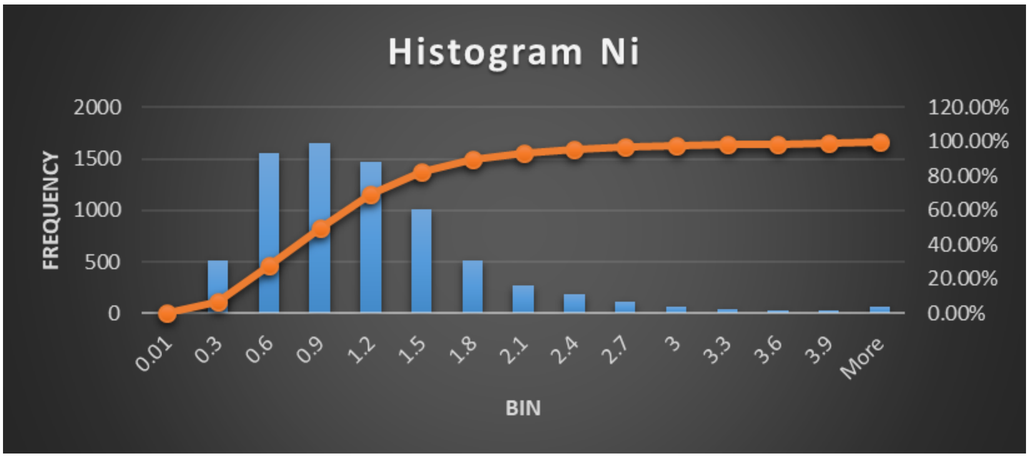

Figure 3. Nickel assay histogram

IV.3. Geological and Topographical Modeling

The constraint of geological and topographical modeling used in this study is shown in Figure 4 and Figure 5.

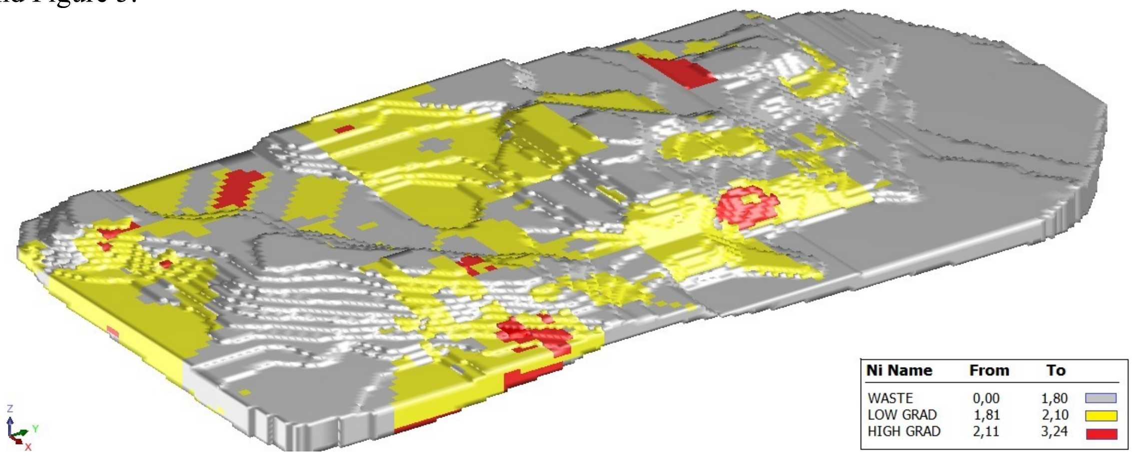

Figure 4. Geological 3D model of the nickel deposit

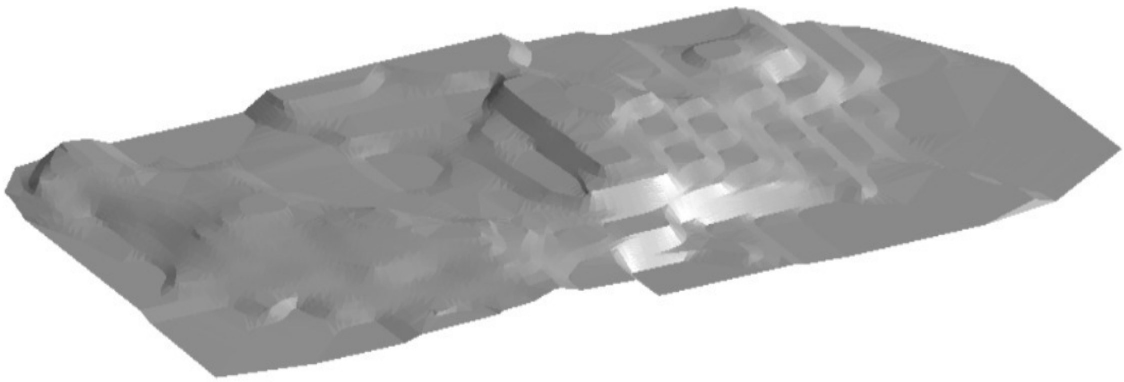

Figure 5. Topographic model of the study area

IV.4. Block Modeling

Variographic analysis before conducting the block modeling is shown in Figure 6. The analysis was conducted in a Geovia^{TM} Surpac.

```
SEARCH PARAMETERS

    ROTATION CONVENTION
         Surpac ZXY LRL

    ANGLES OF ROTATION
         First Axis              75.50
         Second Axis              0.00
         Third Axis               0.00

    ANISOTROPY FACTORS
         Semi_major axis          1.03
         Minor axis               1.96

 OTHER INTERPOLATION PARAMETERS

     Max search distance of major axis            40.000
     Max vertical search distance                 17.000
     Maximum number of informing samples      15
     Minimum number of informing samples      3

 KRIGING TYPE              = ORDINARY KRIGING

VARIOGRAM MODEL = Spherical
     Cumulative sill      0.800000
     Nugget effect        0.000000

     MODEL    C VALUE      RANGE    AZIMUTH     PLUNGE        DIP   SEMI_MAJOR_RATIO     MINOR_RATIO
         1   0.800000     34.000     75.500      0.000      0.000              1.030           1.960

 BLOCK VARIANCE 0.569183
```

Figure 6. Variographic Analysis

Based on the analysis, the major distribution of nickel grade is on N 75.5 E with an area of influence (AoI) of 34 m (Figure 7). The block model of the ore deposits through OK methods shown in Figure 8 and Figure 9.

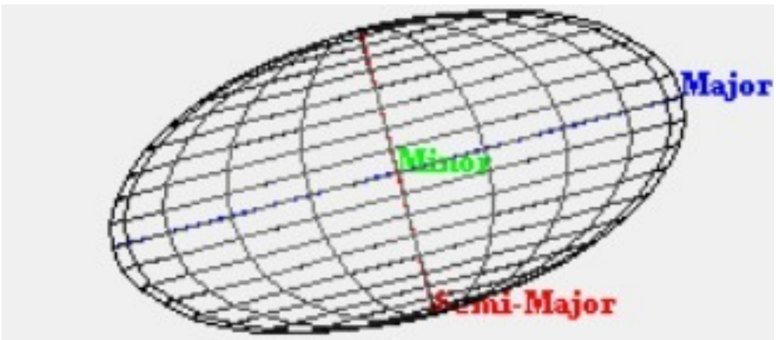

Figure 7. Results of nickel grade anisotropy analysis

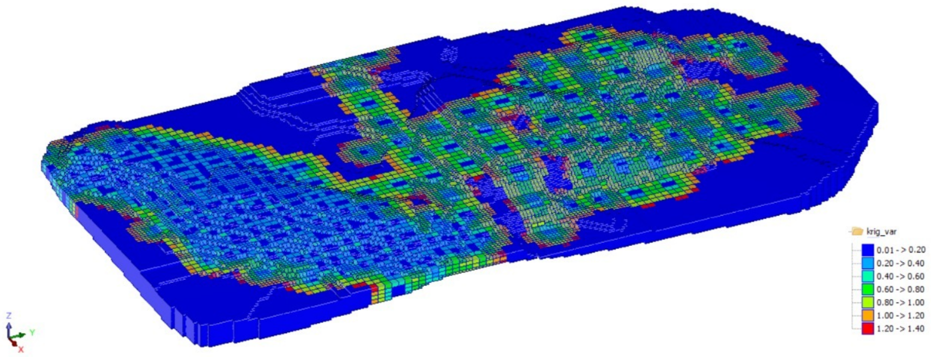

Figure 8. 3D block model showing the distribution of nickel grades.

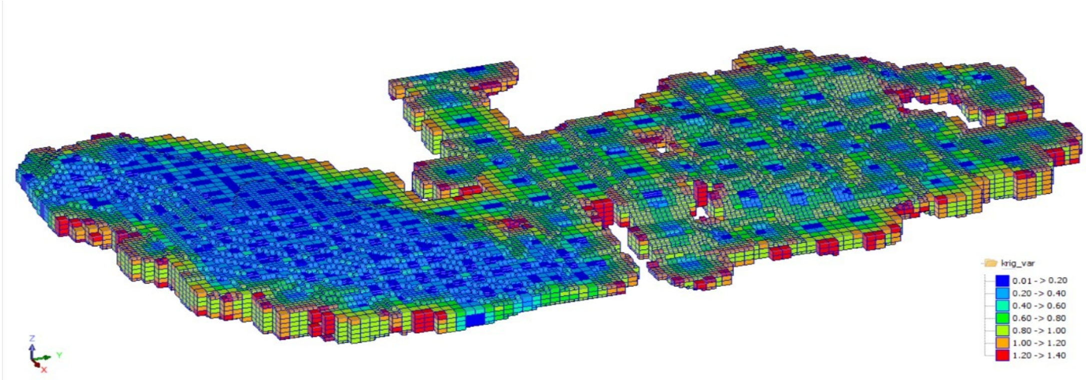

Figure 9. The kriging variance showing the sample configuration index

IV.5. Grade and Reserve Estimation

Grade and reserve estimation displayed on each cross-section (Figure 10). The reserves estimation using OK and NNP are shown in Table 3.

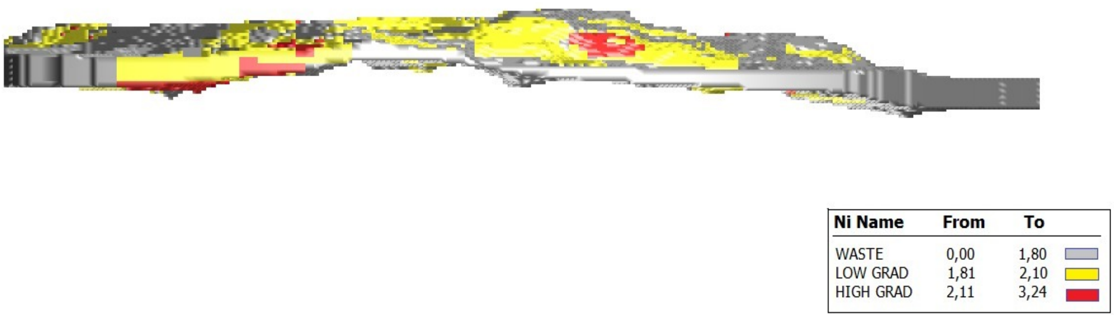

Figure 10. Cross-Section Model

Table 3. Estimated results of nickel ore reserves

	Waste		*Low Grade*		*High Grade*	
	Grade (% Ni)	Tonnage	Grade (% Ni)	Tonnage (Ton)	Grade (% Ni)	Tonnage
OK	1.46	349,014	2.08	171,400	2,43	43.482
NNP	1.46	355,000	2.11	175,000	2.45	44,500

IV.6. Discussion

Based on the result above, the 261 drilling data with a distance of 12.5m for each borehole is giving a coefficient of variation (CV) of 0.70. A descriptive statistical analysis was used to determine the CV. Based on spatial statistical analysis, the nugget and sill are 0.0 and 0.8, respectively. The direction of the major and minor anisotropy based on spatial statistical analysis is indicated as a clear pattern. Hence, a rectangular sampling pattern is proposed to be the most suitable pattern for exploration. This study has indicated a low coefficient of variation from data so that choosing OK or NNP estimation methods are flexible. However, spatial statistical analysis has shown that nickel grade is not uniform. This result may indicate that selection of estimation methods should be conducted carefully based on several parameters. The digitization of the limonite and saprolite zone was done through a hard boundary method from the geological model. The reserve estimation was conducted from the geological model. As a result, reserve estimation modeling is quite representative. The low grade and high-grade zones are displayed thoroughly and can be used for further study.

Table 3 is an estimated result of ore reserve based on reserve estimation modeling. The saprolite layer has a greater total volume of nickel ore than the limonite layer. This result indicates a concentration of nickel deposits in that layer.

V. CONCLUSION AND FURTHER RESEARCH

Based on the result and discussion above, there are several highlight points of this study. The rectangular drilling pattern is proposed as the most suitable drilling pattern in the area based on variograph analysis. The data has a relatively low CV (0.7). The reserve estimation methods selections, namely OK and NNP, must be carried out carefully for nickel ore deposit. The estimated nickel deposit is concentrated in a saprolite layer. The reserves estimation model has shown a distinguished model of low and high-grade zones, and it can be used for further study. The findings of this study are quite useful, but this study only discusses aspects of the geological domain, so further research is needed on the grade estimation method for estimating ore grades.

Suggestions for further research are to analyze nickel ore block grade estimation methods, for example, NNP (nearest neighbor polygon, inverse distance weighting, linear and non-linear kriging.

VI. REFERENCE

Krzemień, A. Fernández, P. R., Sánchez, A. S., and Álvarez, I. D., 2016. Beyond the pan-European standard for reporting of exploration results, mineral resources and reserves, Resources Policy September Volume 49 Pages 81-9.

Porwal, I. Álvarez, G., Markwitz, V., Craig, T. C. M., and Mamuse, A., 2010. Weights-of-evidence and logistic regression modeling of magmatic nickel sulfide prospectivity in the Yilgarn Craton, Western Australia Ore Geology Reviews Volume 38, Issue 3Pages 184-196 A.

Putzolu, I., Abad, G., Balassone, M., Boni, L., and Santoro, 2020. Parent rock and climatic evolution control on the genesis of Ni-bearing clays in Ni-Co laterites: New inferences from the Wingellina deposit (Western Australia) Ore Geology Reviews Volume 120 Article 103431 F.

Scarciglia, F., Critelli, S., Borrelli, L, Coniglio, S., and Perri, F., 2016. Weathering profiles in granitoid rocks of the Sila Massif uplands, Calabria, southern Italy: New insights into their formation processes and rates, Sedimentary Geology Volume 336 Pages 46-67.

Ding, Y., Cui, W., Zhang, S., Hui, H., and Song, Y., 2019. Multi-state operating reserve model of aggregate thermostatically-controlled-loads for power system short-term reliability evaluation, Applied Energy Volume 241Pages 46-58.

Hadji, R., Boumazbeur, A., Limani, Y., Baghem, M., and Demdoum, A., 2013. Geologic, topographic and climatic controls in landslide hazard assessment using GIS modeling: A case study of Souk Ahras region, NE Algeria Quaternary International Volume 302 Pages 224-237.

Bargawa, W. S., 2016. Mineral Resource Estimation Using Weighted Jackknife Kriging. Conference proceedings, in AIP Conf. Proc. 1755, 2016, pp. 120001-1-120001-6.

Zulkarnain, I., and Bargawa, W. S., 2018. Classification of Coal Resources Using Drill Hole Spacing Analysis (DHSA). Journal of Geological Resource and Engineering 6, pp. 151-159.

Bargawa, W. S., and Tobing, R. F., 2020. Iron ore resource modeling and estimation using geostatistics, AIP Conference Proceedings 2245, 070016

Yuan, S., Zhou, W. T., Li, Y. J., and Han, Y. X., 2020. Efficient enrichment of nickel and iron in laterite nickel ore by deep reduction and magnetic separation, Transactions of Nonferrous Metals Society of China Volume 30, Issue 3, Pages 812-822.

Ramesh, S. V., Teegavarapu, V., and Chandramouli, 2005. Improved weighting methods, deterministic and stochastic data-driven models for estimation of missing precipitation records Journal of Hydrology Volume 312, Issues 1–4Pages 191-206.

Ilyas, A., Kashiwaya, K., and Koike, K., 2016. Ni grade distribution in laterite characterized by geostatistics, topography, and the paleo-groundwater system in Sorowako, Indonesia Journal of Geochemical Exploration Volume 165 Pages 174-188.

Jiang, J., and Zhu, Y., 2017. Geology and geochemistry of the Jianchaling hydrothermal nickel deposit: T–pH–fO2–fS2 conditions and nickel precipitation mechanism Ore Geology Reviews Volume 91 Pages 216-235.

Guo, X., and Dias, D., 2020. Kriging based reliability and sensitivity analysis – Application to the stability of an earth dam Computers and Geotechnics Volume 120 Article 103411.

Coombes, J., 2008. The Art and Science of Resource Estimation. Coombes Capability, Perth.